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SPACE ENVIRONMENT FACILITY FOR ELECTRIC PROPULSION SYSTEMS RESEARCH

by Robert C. Finke, Arthur D. Holmes, and Thomas A. Keller

*Lewis Research Center
Cleveland, Ohio*

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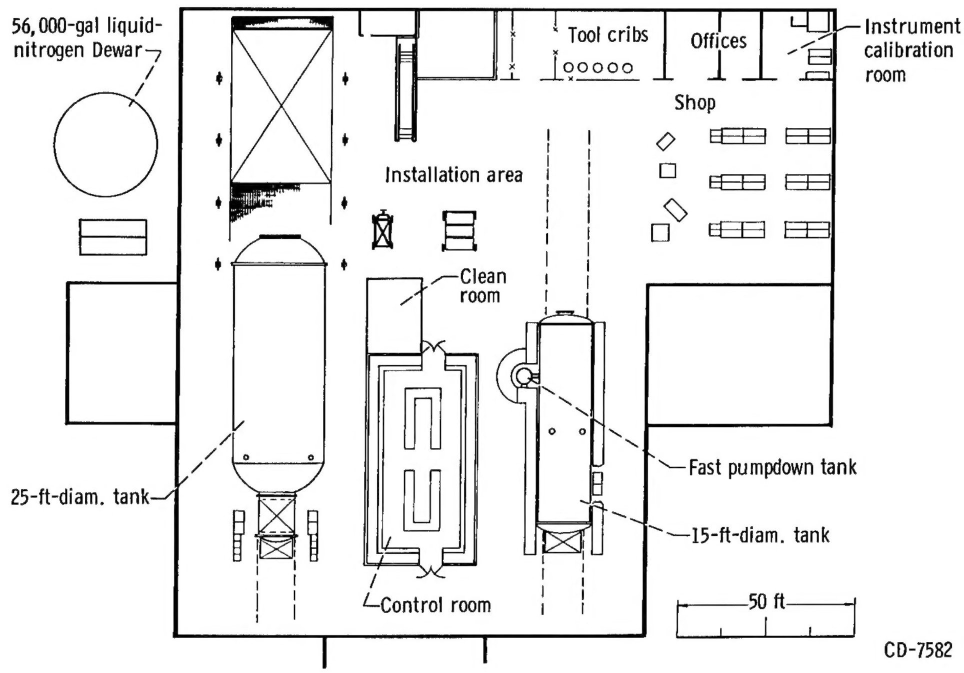
SUMMARY

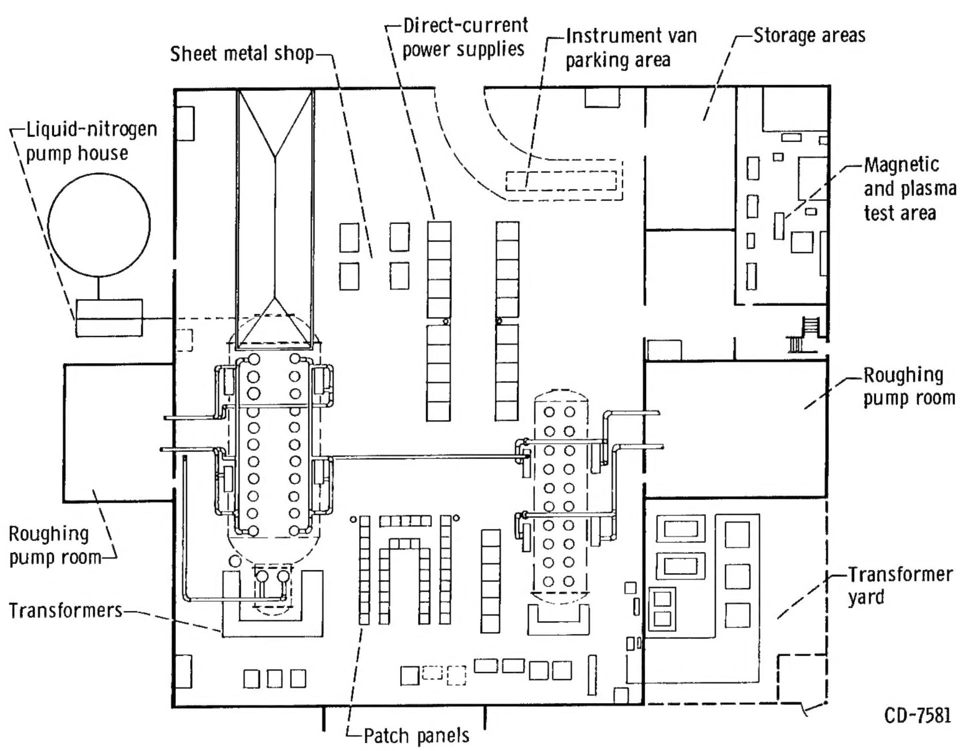
A facility containing 15- and 25-foot-diameter space-environment tanks and support equipment is described. The facility is designed for testing ion and plasma thrustors, spacecraft, and related components at pressures in the 10^{-7} torr range. Total pumping capacity in the 10^{-5} torr range for air has been measured at 250 000 liters per second and for hydrogen at 660 000 liters per second. The pumping systems and 28 000-square-foot liquid-nitrogen-cooled condenser are described. Data are presented on an auxiliary fast pumpdown tank that simulates ambient pressures encountered during a booster launch to 10^{-6} torr range in approximately 2 minutes. Pertinent information concerning a spin test apparatus and thrustor installation method is also included. An electrical and instrumentation system is described consisting of 2 megawatts of 20-kilovolt direct-current power, a 2000-cable patch board network, a 600-channel thermocouple system, and a 400-channel digital data recorder. An annunciator system is provided to indicate status of operating equipment. Some aspects of safety are considered, including interlocking, personnel protection, and procedures.

INTRODUCTION

The facility described is the electric propulsion laboratory of the Lewis Research Center. It was designed for testing ion and plasma thrustors, spacecraft, and other equipment in simulated space conditions. The facility consists of an office and attached operations building. The operations building houses two space-environment tanks, auxiliary and test equipment, and shop support facilities. The layout of each of the two floors of the operations building is shown in figure 1. The test area of the two tanks is on the first floor. The 25-foot-diameter by 70-foot-long tank (fig. 2(a)) is intended

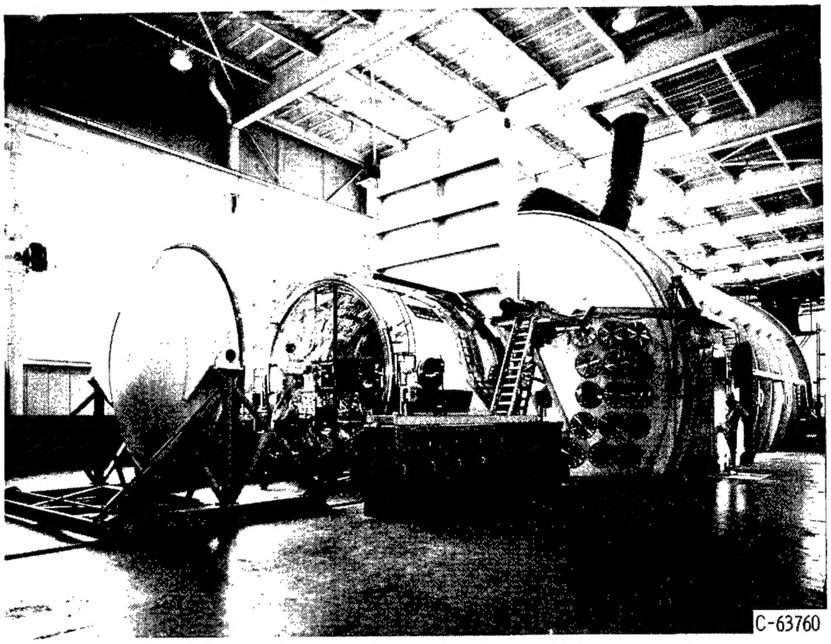


(a) First floor.

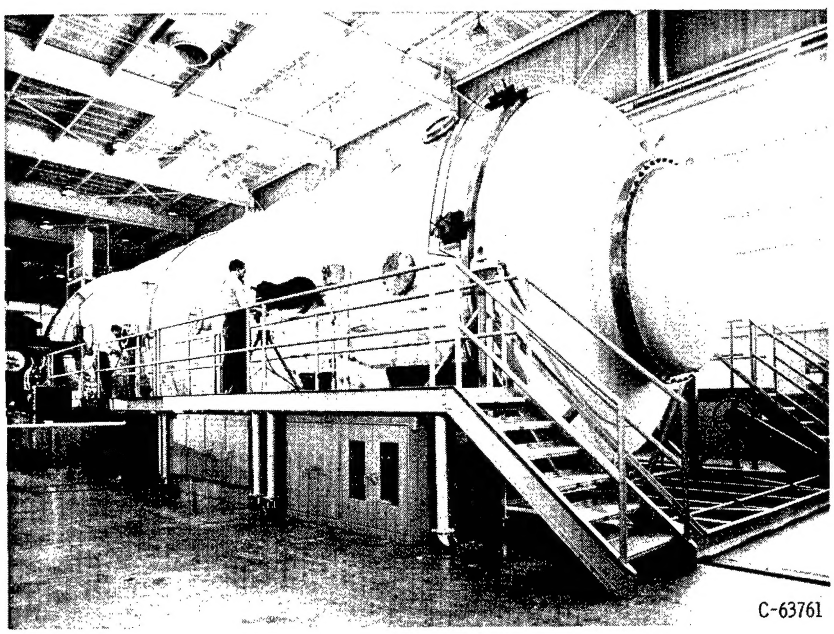


(b) Ground floor.

Figure 1. - Operations building.



(a) 25-Foot-diameter tank.



(b) 15-Foot-diameter tank.

Figure 2. - Vacuum facilities.

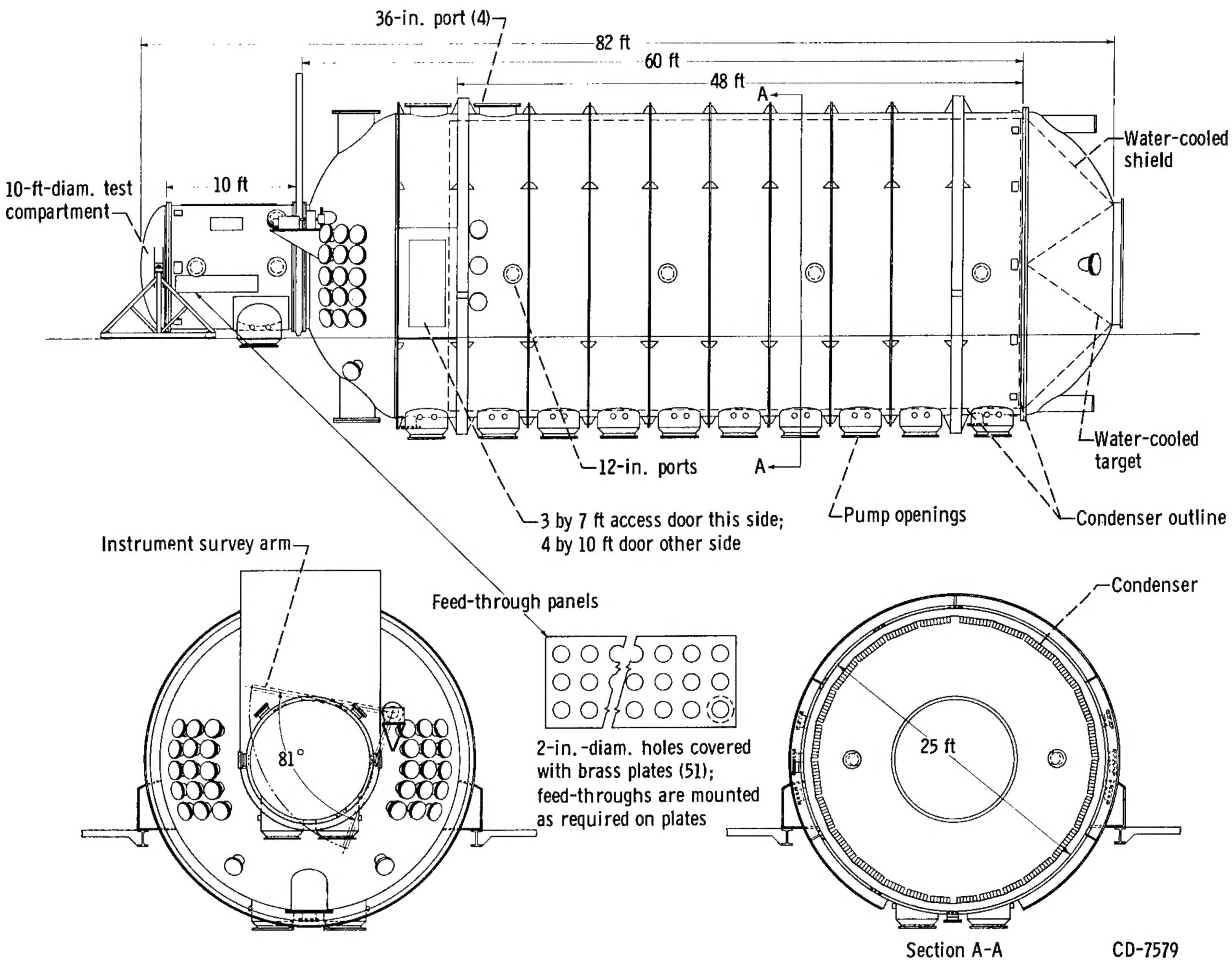


Figure 3. - 25-Foot tank layout.

primarily for testing electric thrustors that utilize condensable propellants. The 15-foot-diameter by 63-foot-long tank (fig. 2(b)) is designed for both space environmental tests and thrustors having noncondensable propellants. Tests can be conducted in both tanks simultaneously from the control room located between the tanks. The first floor also contains an instrument calibration area, shop, clean room, and thrustor installation area. The power supplies, pumping systems, instrument van parking, sheet metal shop, and storage areas are located on the ground floor.

25-FOOT-DIAMETER TANK

Description

The 25-foot tank is designed primarily for testing thrustors that employ condensable

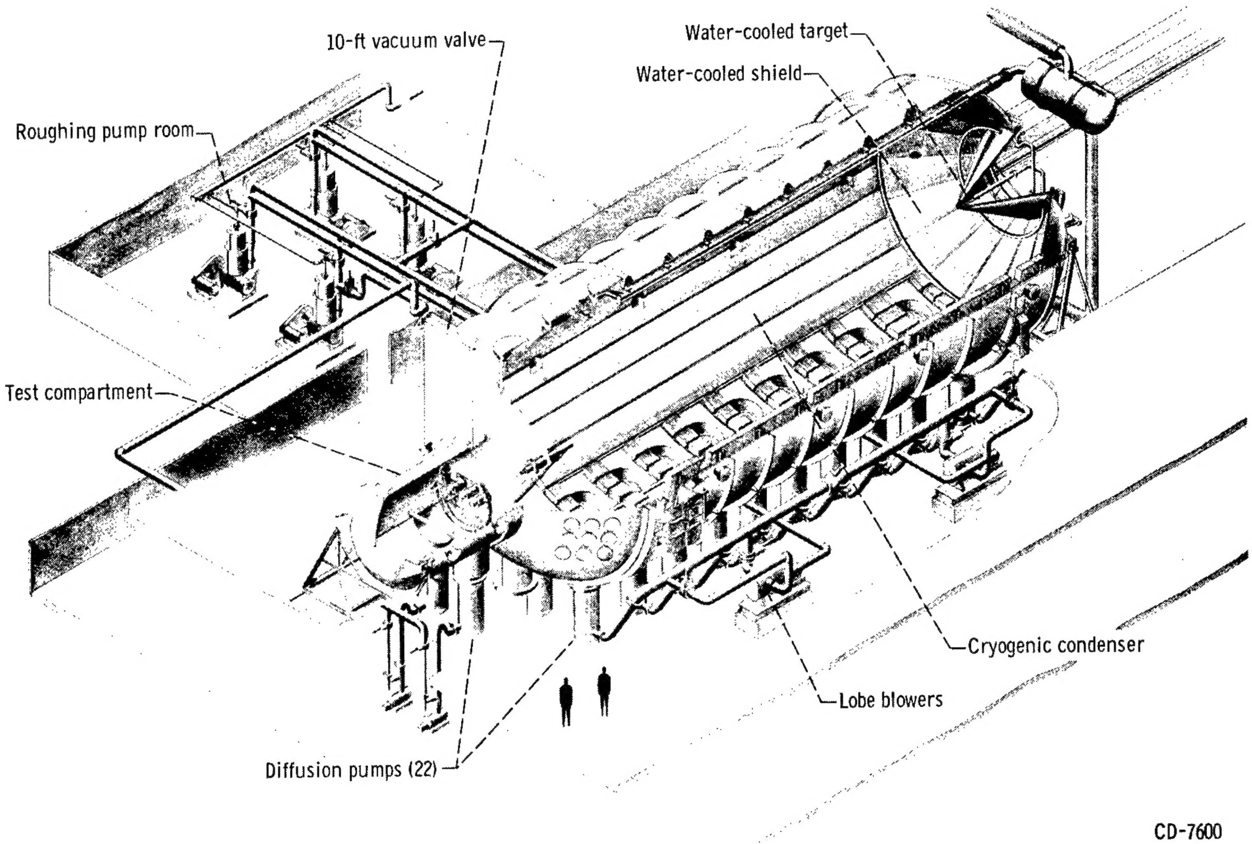


Figure 4. - Cutaway view of 25-foot-diameter tank.

propellants. It is constructed from a 9/16-inch-thick steel clad material. The interior layer consists of 1/8-inch 304 stainless steel, while the outer layer is mild steel. The arrangement of components, the major dimensions, the details of the vacuum feed-through panels, and other related information of the 25-foot-diameter tank are shown in figure 3. Thrustors may be tested individually or in arrays; the primary limitations are mounting space and/or propellant condensing capacity.

The condenser system, which is designed to absorb up to 1 megawatt of power, is composed of three elements: the cryogenic condenser, the water-cooled target, and the water-cooled shield. These components are shown in the cutaway view of the tank (fig. 4). The cryogenic condenser is a copper honeycomb cooled by liquid nitrogen. This portion of the condenser can absorb up to 0.1 megawatt. The water-cooled target is designed to absorb 0.9 megawatt. The target is a conical-shaped stainless-steel double-walled structure, 8 feet from the bottom to the apex and 10 feet in diameter. Water is introduced at the apex of the target and is conducted through a helical passage to a manifold at the base of the target. In addition to the target, a water-cooled shield protects the interior surface of the 25-foot head. The shield is fabricated in pie-shaped segments from embossed stainless-steel plates.

The test compartment is separated from the main tank by a 10-foot-diameter vacuum

gate valve of stainless-steel construction. The valve disk is raised and lowered by a counterbalanced chain, which is operated by an electric motor mounted exterior to the valve body with the drive shaft going through a rotating vacuum seal. The gate disk with two O-rings vacuum seals in one direction. To accomplish the sealing of the disk against the O-ring sealing surface, eight pneumatically operated pistons are used to hold the disk in place until the differential pressure across the valve is sufficient to seal it. Dry nitrogen gas is used to activate the pistons. The time required to raise or lower the disk is 5 minutes. The utility of the tank is increased by the capability of isolating the test compartment because thrustor changes can be made without warming the condenser or bringing the main tank to atmosphere.

Pumping System

The tank is equipped with a vacuum system to simulate space pressure conditions with normal testing in the 10^{-7} torr range. The pumping system is essentially identical for each tank and is shown for the 25-foot tank on figure 4. Air is pumped out of each tank through twenty 32-inch diffusion pumps into four lobe-type blowers installed in parallel. Two additional diffusion pumps are installed on the test compartment of the 25-foot tank. Following the blowers are four rotating piston-type roughing pumps. During the pumpdown cycle, the blowers are bypassed until the roughing pumps have lowered the system pressure to 15 torr. The blowers and diffusion pumps are then activated, and by the time the system reaches 2×10^{-3} torr the diffusion pumps have become effective. All eight roughing pumps can be used on one tank if desired. The tanks, containing no test apparatus, have been evacuated to 6×10^{-6} torr in less than 2 hours. Backstreaming of

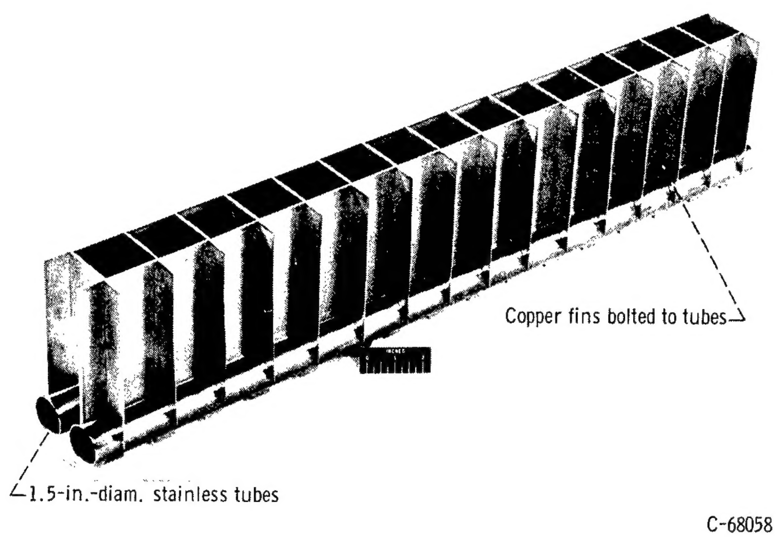


Figure 5. - Section of honeycomb condenser.

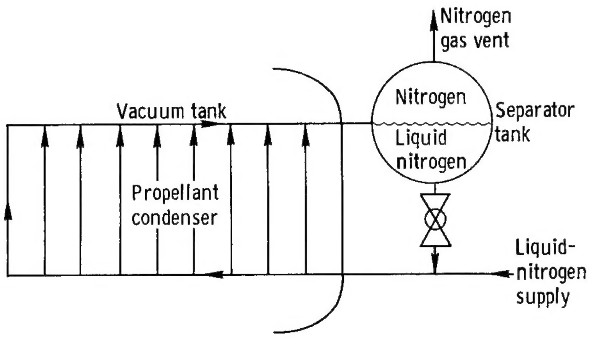


Figure 6. - Flow diagram of 25-foot-diameter tank condenser system.

oil from the diffusion pumps into the tanks is reduced to negligible amounts by water-cooled caps on top of the diffusion pump jet assembly and by liquid-nitrogen-cooled chevron-shaped baffles over the intakes of the pumps. Cold traps have been installed between the mechanical and diffusion pumps on the 25-foot tank. These traps protect the mechanical pumps from condensable propellants.

Cryogenic pumping is also used in maintaining tank pressures during thrustor operation. A finned liquid-nitrogen-cooled condenser lines the major portion of the 25-foot tank. The prime function of this cold surface is to condense and trap propellant from the thrustor exhaust. The condenser consists of a rectangular copper honeycomb structure built on 1.5-inch-diameter stainless-steel tubes as shown in figure 5. There are 28 000 square feet of copper surface designed to operate between -300° and -280° F, depending on the thrustor power load. The honeycomb material is bolted to the stainless-steel tubing and may be replaced if eroded by the exhaust beam.

The liquid-nitrogen system furnishes nitrogen to the propellant condenser, oil-diffusion-pump traps, and foreline traps. In addition, the liquid-nitrogen system furnishes gaseous nitrogen to raise the tank pressure to atmospheric conditions. The nitrogen system has a 56 000-gallon storage Dewar that is insulated by vacuum and perlite. There are two 100-gallon-per-minute pumps to supply liquid nitrogen to the oil diffusion traps, foreline traps, and propellant condenser at 40 pounds per square inch gage pressure. The liquid-nitrogen system for the diffusion pump traps and foreline traps is operated with a back pressure of 25 pounds per square inch gage, which gives a single-phase flow. Two-phase flow occurs in the propellant condenser. The nitrogen passes through a separator tank where the liquid nitrogen is returned to the inlet and the gaseous nitrogen is vented to atmosphere as shown in the flow diagram (fig. 6).

Hot nitrogen is used to warm the propellant condenser. The condenser warmup system has a separate blower and heat exchanger. The liquid nitrogen is first removed from the propellant condenser by a 50-gallon-per-minute transfer pump and returned to the storage Dewar. The gaseous nitrogen is then circulated through the 126-kilowatt heat exchanger and through the condenser. As the condenser surfaces warm up and the gas pressure increases, the gas is vented to the atmosphere to maintain a pressure of 15 pounds per square inch gage in the condenser. Another part of the nitrogen system contains a 500-kilowatt heater to vaporize liquid nitrogen. The vaporized nitrogen can be vented into the vacuum chamber to bring the chamber to atmospheric pressure.

Tank Pressure Instrumentation

Tank pressure is continuously monitored at a number of points by multiple Pirani and ionization gage systems. Each tank has an independent pressure monitoring system.

The Pirani gage system is a 24-channel (for each tank), pushbutton-operated unit, employing a single-channel Pirani gage box to provide power and readout for the system. Tube switching is accomplished by a 24-channel stepping switch arranged so that it automatically runs to the channel for which a pushbutton has been depressed. All channels have individual zero, and calibration controls are preset so that no adjustments are required when switching from tube to tube.

The multiple ionization gage systems, like the Pirani systems, are 24-channel devices. The selection of an ionization tube is determined by depressing the appropriate pushbutton. Bayard-Alpert tubes with iridium filaments are used with the system. The ionization system has eight rotary switches on the panel to power the degassing grids in the tubes (3 tubes/switch). The gage system will record continuously, on a strip chart recorder, the output of the tube being read. The scale on the recorder is in decades from 1×10^{-3} to 1×10^{-8}, and the recorder pen is shifted as the gage box switches range. The gage box will shift its range automatically as the pressure varies in the tank. Between readings, the gage filaments are kept at a reduced temperature to prevent condensation of vapor on the walls of the tube and absorption of gases by the tube elements.

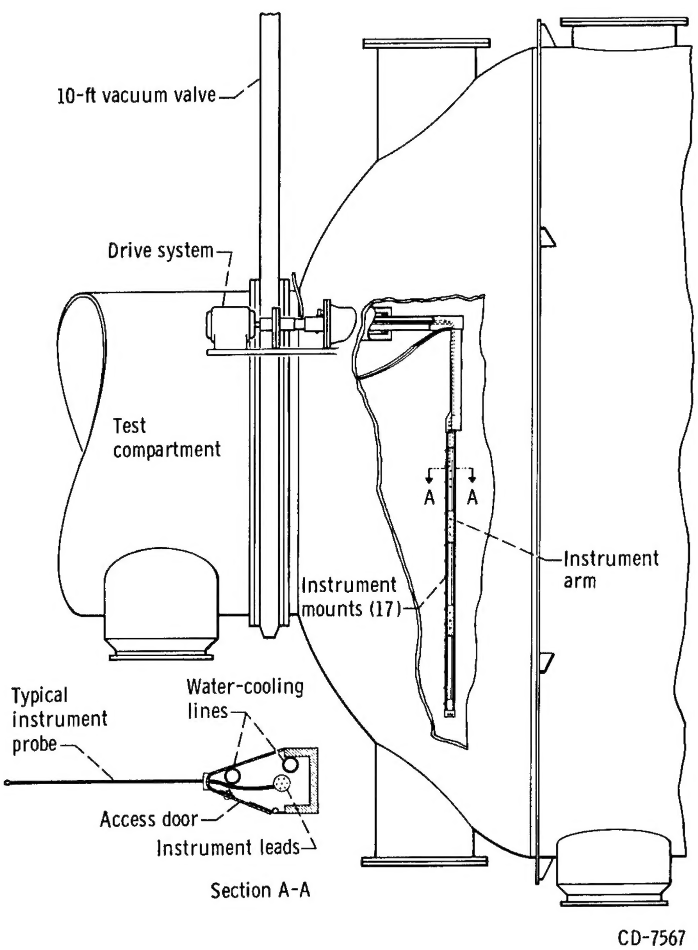


Figure 7. - Instrument survey arm.

Data from the thrustor ion beam can be obtained from sensing instruments mounted on an instrument survey arm. A schematic of the water-cooled arm is shown in figure 7. It sweeps an arc in a plane perpendicular to the beam. The motion of the arm may be stopped and reversed at any point in the 81° sweep angle. The speed can be varied from

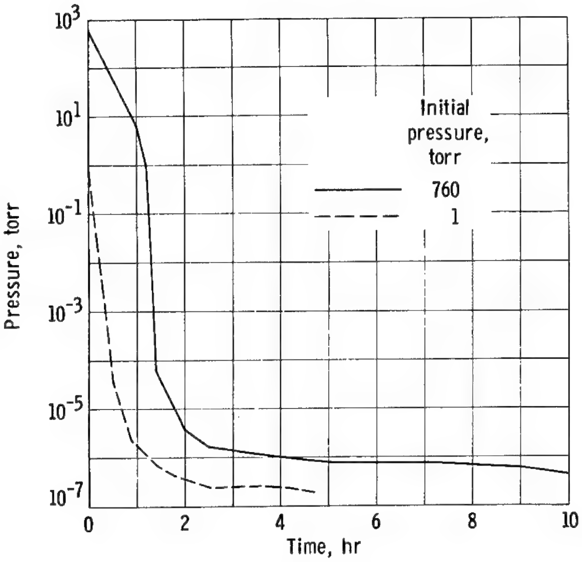


Figure 8. - Pumpdown rate with 20 oil diffusion pumps, liquid-nitrogen-cooled traps, and condenser. 25-Foot-diameter tank.

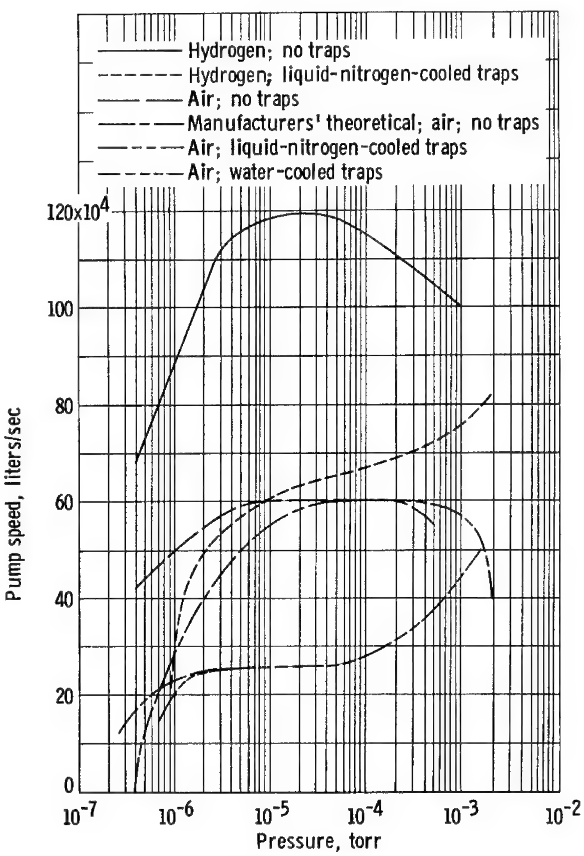


Figure 9. - Pumping speed data for 25-foot tank.

4 seconds to 4 minutes per sweep.

Seventeen instrument mounting pads are available along the leading edge of the arm at 6-inch intervals. The pads consist of 3/4-inch-diameter disks with a center tapped hole. Each disk is welded directly to the arm structure. Leads from the sensing device are threaded through the tapped hole prior to instrument mounting. The leads are attached to the inside of the hollow arm and conducted up to the end of the arm. The sensing lead harness is then brought out of the tank through a vacuum seal.

Tank Performance

The performance characteristics of the 25-foot-diameter tank have been determined with the pump traps at -320° F and the main tank condenser at both ambient temperature and -320° F. Calibrated flows of both air and hydrogen have been investigated.

The tank pumpdown rate with the condenser at -320° F is shown in figure 8. Two curves are presented: (1) starting at atmosphere after the tank had been open for several days, and (2) starting at 1 torr, the normal point for initiating pumping between phases of a test. These data were taken after the tank had been in use for approximately 2 years and the condenser was coated with mercury collected from ion-thrustor operation. The tank contained apparatus that included a 20-foot-diameter movable collector with drive system, a fixed 20-foot-diameter collector, an instrument survey arm, and several miscellaneous wiring harnesses.

Normally, model modifications are made

TABLE I. - PUMPING CHARACTERISTICS OF 25-FOOT-DIAMETER TANK

Condition	Tank condenser, -320° F; pump traps, -320° F	Tank condenser, 60° F; pump traps, -320° F
Maximum system pump speed for air, liters/sec	----	[a]250 000
Maximum system pump speed for hydrogen, liters/sec	----	[b]660 000
Ultimate pressure in new clean tank, torr	6.5×10^{-9}	1.4×10^{-7}
Time required to obtain ultimate pressure, hr	35.0	20.0
Ultimate pressure in tank (after 2 yr use), torr	9.0×10^{-9}	----
Time required to obtain ultimate pressure, hr	26.0	----
Time required to open tank to atmosphere, hr	3.0	----
Time required to open test compartment to atmosphere, hr	1.8	1.8

[a]At 10^{-4} to 10^{-6} torr.
[b]At 10^{-4} torr.

by closing the 10-foot valve and bringing only the test compartment to atmospheric pressure. Then, the compartment is closed and pumping initiated. With three 20-centimeter-diameter ion thrustors installed the pressure reached 2×10^{-5} torr in 55 minutes. At this time the 10-foot-diameter valve was opened. Thirty minutes later the tank pressure reached 2.0×10^{-6} torr. Typical pumping speed data are shown in figure 9. Pertinent characteristics for the 25-foot tank, including the calibrated air and hydrogen flows, are given in table I.

After a test run, 1.8 hours are required to cool the diffusion pumps and bleed the test compartment to atmospheric pressure. Additional time may be required to remove toxic vapors prior to entering.

During the investigation reported in reference 1, a 65-hour continuous run was made with a 50-centimeter-diameter electron-bombardment thrustor. A beam power of 22.5 kilowatts was maintained during this period. Mercury was the propellant. The test

Figure 10. - Thrustor installation in cart and installation fixture.

compartment pressure was 2×10^{-6} torr at the start of the test and reached 7×10^{-7} torr after 30 hours. At 65 hours the pressure was 6×10^{-7} torr. The tank had accumulated several hundred hours of mercury thrustor time when these data were taken.

Thrustor Installation

Prior to testing, thrustors are mounted on a thrustor cart in the shop. Power, instrument, cooling, and heating leads are fitted from the cart to a fixture that duplicates the tank feed-through positions (fig. 10). When the tank is available for testing, the thrustor cart is transferred to the tank test compartment. The cart is rolled into the operating position on a set of rails. Thrustor leads are connected, the compartment door closed, and the system checked out. The test compartment is then evacuated by a separate pumping system. After the 10-foot valve is opened the apparatus is ready to be tested.

Figure 11 gives an indication of the mounting space required by an array of nine electron-bombardment thrustors. Thirty-seven thrustors of this size (16-in. o.d.) could be installed.

The investigations such as reported in references 1 to 3 are typical of the tests conducted in the 25-foot tank.

15-FOOT-DIAMETER TANK

Description

The 15-foot-diameter tank is 63 feet long and was designed primarily for environmental testing of space packages and plasma thrustors. It is constructed from the same material as the 25-foot tank. One end of the tank is readily removable to allow large

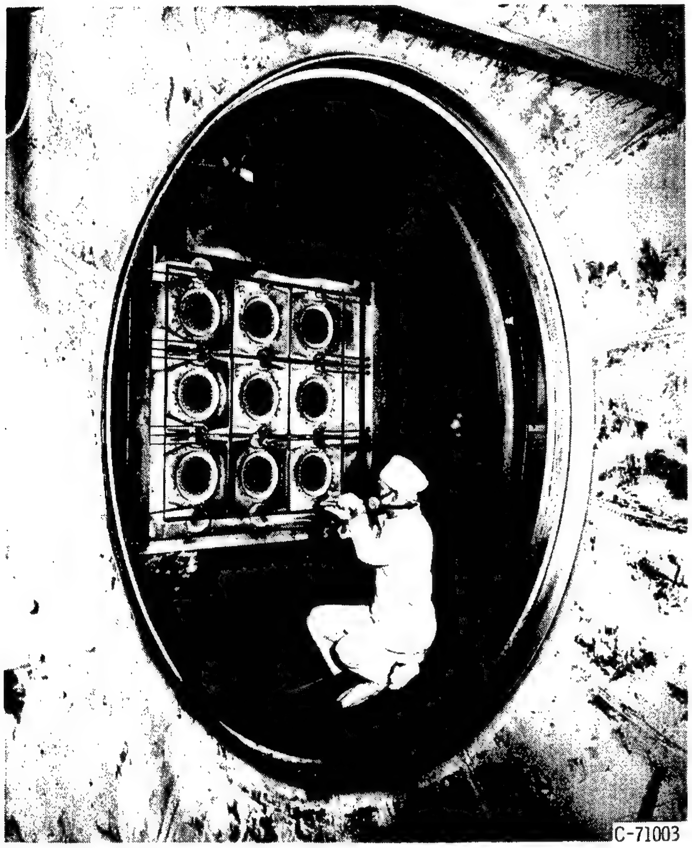


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Figure 11. - Nine ion thrustor array.

units to be installed conveniently for testing. The layout of the tank is shown in figure 12. Power, gas, and liquids may be supplied to the test apparatus through lines passing through any of the eight sets of feed-through panels.

Along the horizontal centerline of the tank are eleven 12-inch viewing ports. For ultraviolet applications quartz windows may be substituted for the standard glass units. The windows can be removed and exchanged for plates with instrumentation feed-throughs and other devices. One 24-inch-diameter and six 36-inch-diameter ports are available for special installation of equipment, services, and instrumentation as required. The size and location of the ports are shown in figure 12. All port openings are sealed with buna N O-rings. The pumping system for the 15-foot tank is identical to the 25-foot tank. The condenser for the 15-foot tank is fabricated from copper sheet with integral tubes and is painted black. Nitrogen is furnished to the 15-foot tank from the same source that supplies the 25-foot tank. To operate all systems in the 15- and 25-foot tanks at maximum capacity, 830 gallons per hour of liquid nitrogen are required.

Tank Performance

The performance characteristics of the 15-foot-diameter tank have been determined under several conditions and are tabulated in table II. The pumping speeds for both tanks are identical, as previously mentioned, and are plotted in figure 9.

After a test with the condenser at ambient temperature and the pump traps at 60° F, approximately 60 minutes are required to cool the diffusion pumps and vent the tank to atmosphere. If the condenser and traps are at -320° F, 3 hours are required to bring the tank to atmospheric pressure. Additional time is required for ventilating the tank

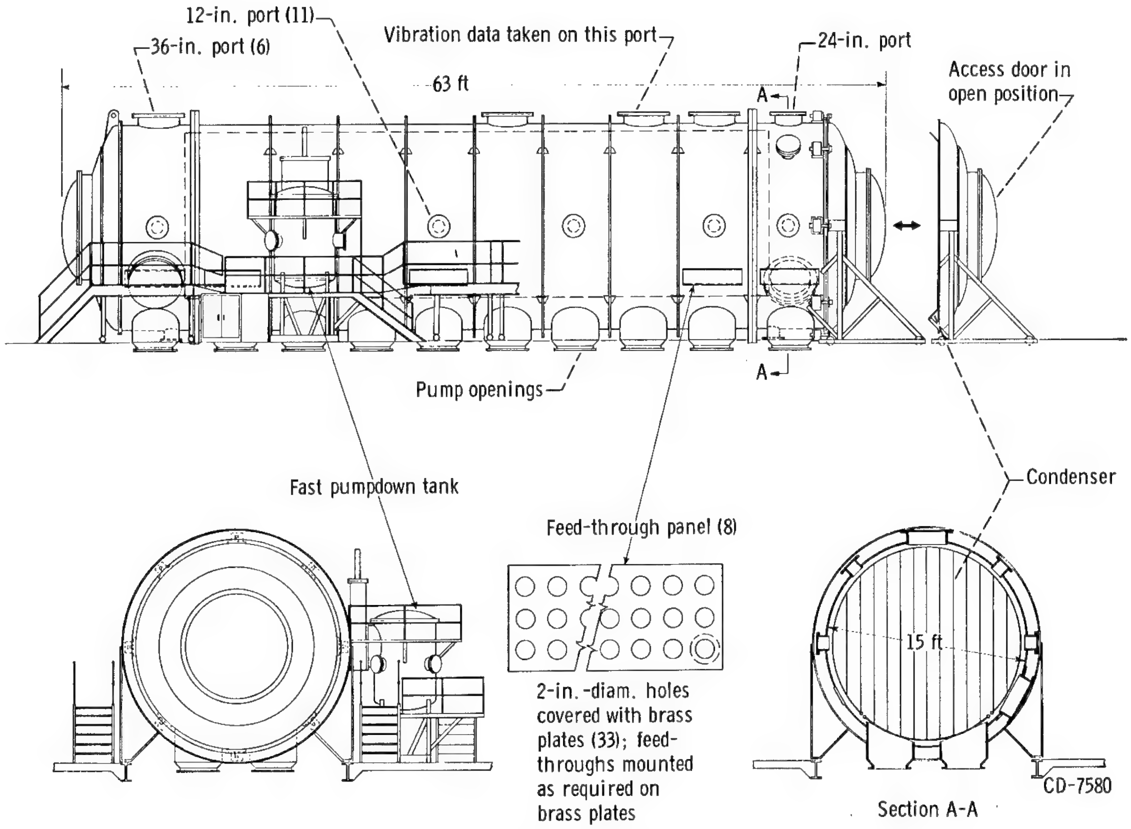

Figure 12. - 15-Foot tank layout.

TABLE II. - PERFORMANCE CHARACTERISTICS OF 15-FOOT-DIAMETER TANK

Condition	Tank condenser, 70° F; pump traps, -320° F	Tank condenser, 70° F; pump traps, 60° F	Tank condenser and pump traps, -320° F
Maximum system pump speed for air, liters/sec	[a]250 000	[a]250 000	------
Maximum system pump speed for hydrogen, liters/sec	[b]660 000	------	------
Ultimate pressure, torr	1.3×10^{-8}	4.0×10^{-7}	1.0×10^{-8}
Time required to obtain the ultimate pressure, hr	17.0	11.0	17
Time required to enter tank after test, hr	2	1	~3

[a]At 10^{-4} to 10^{-6} torr.
[b]At 10^{-4} torr.

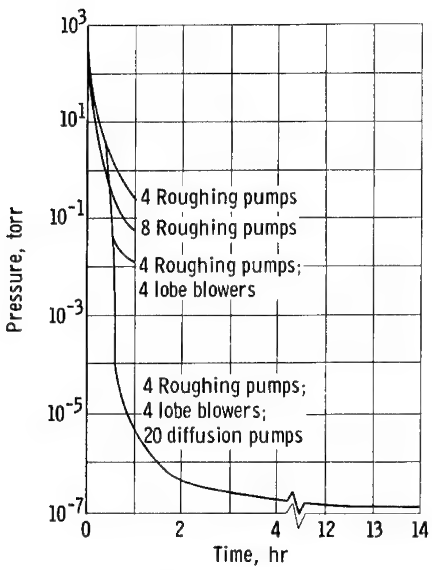

Figure 13. - Pumpdown rate for 15-foot tank.

prior to entering if toxic vapors are generated during the test.

The tank pumpdown rates for four pumping configurations are shown in figure 13. For the configurations utilizing both diffusion and mechanical pumps, the roughing pumps were activated at time zero. The lobe blowers were turned on in approximately 17 minutes at a pressure of 15 torr. The heaters on the diffusion pumps were energized approximately 10 minutes after closing the tank; the pumps became effective in 32 minutes. The main condenser and the pump traps were cooled to -320° F at 10^{-6} torr. During this pumpdown the tank contained the following: the space electric rocket test (SERT) payload, a 30-kilowatt arc-jet thrustor, a 10-centimeter-diameter electron-bombardment thrustor plus the associated harnesses, an instrument probe, an 8- by 8-foot sheet-metal baffle, and a 3-foot conical water-cooled heat exchanger. After 11 hours, the pressure had dropped to 1.5×10^{-7} torr and remained essentially constant for 3 more hours when the run was concluded.

Another test series was run with the tank condenser and traps warm, the tank containing the equipment previously described. During one test, only four roughing pumps and four blowers were in operation. An ultimate pressure of 1.2×10^{-2} torr was obtained. Starting at atmospheric pressure the tank was pumped in 1 hour to 0.3 torr with four roughing pumps and to 8×10^{-2} torr with eight roughing pumps. These data are also shown in figure 13.

With a clean and empty tank, ultimate pressures of 4×10^{-7} and 1.3×10^{-8} torr were obtained with water-cooled and liquid-nitrogen-cooled traps, respectively.

Typical tests conducted in the 15-foot-diameter tank include the evaluation of a 1- and a 30-kilowatt arc jet and the SERT payload. The 1-kilowatt arc jet was tested with tank pressures near 8×10^{-5} torr. The results of this investigation are reported in references 4 and 5. During the 30-kilowatt arc-jet test a tank pressure of 0.85 torr was recorded with a hydrogen flow of 0.28 gram per second. The SERT test required activation of high-voltage systems, ignition of pyrotechnics, and ignition of ion thrustors during a typical tank run. Typical pressure fluctuations resulting from equipment and thrustor operation (maximum beam current was 250 ma) ranged from 6×10^{-6} to 8×10^{-6} torr. The operation of three pyrotechnic devices caused the pressure to decrease from 5×10^{-7} to 9×10^{-5} torr. The devices were ignited over a 5-second interval, and 17 seconds elapsed after the last firing before the tank pressure recovered.

An air bearing, which bleeds air into the tank for a known back pressure and flow

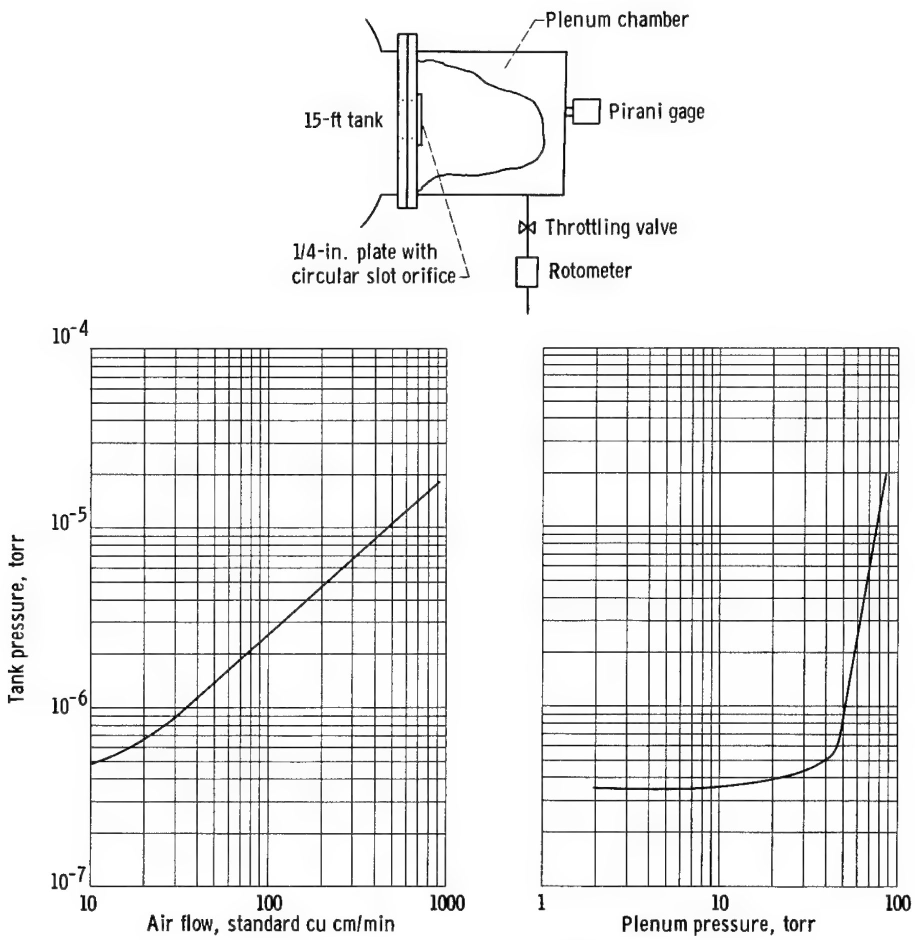

Figure 14. - Simulated air bearing leak.

rate, was required for a space payload test. To determine the effect of such a device, air was bled into the tank through a special calibration system shown in figure 14. Air flows into the tank through a 0.0005-inch circular slot, 2 inches in diameter, from a plenum chamber where the pressure can be controlled. The chamber was approximately 9 inches long, 6 inches in diameter, and mounted to a tank port. With the 15-foot tank at vacuum, the pressure in the plenum was controlled by throttling the quantity of supply air at atmospheric pressure. A rotometer was utilized for measuring the flow of supply air. Chamber pressure was measured with a Pirani gage. Data-indicated tank pressure, chamber pressure, and flow rates for this system are also shown in figure 14.

Tank Vibration Characteristics

Vibration data were taken on the 36-inch port located on the top centerline of the 15-foot tank shown in figure 12. Data were recorded with the tank at vacuum and all

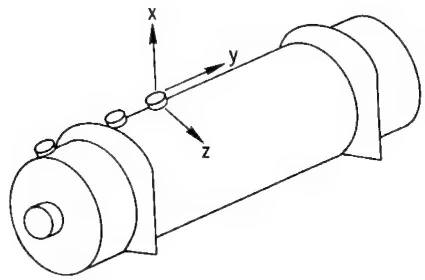

Figure 15. - Axis notation.

TABLE III. - VIBRATION DATA FOR

15-FOOT TANK

Axis	Frequency, cps	Displacement, in.	Maximum g load
x	3000	Below 10^{-7}	0.005
y	↓	↓	.12
z			.006

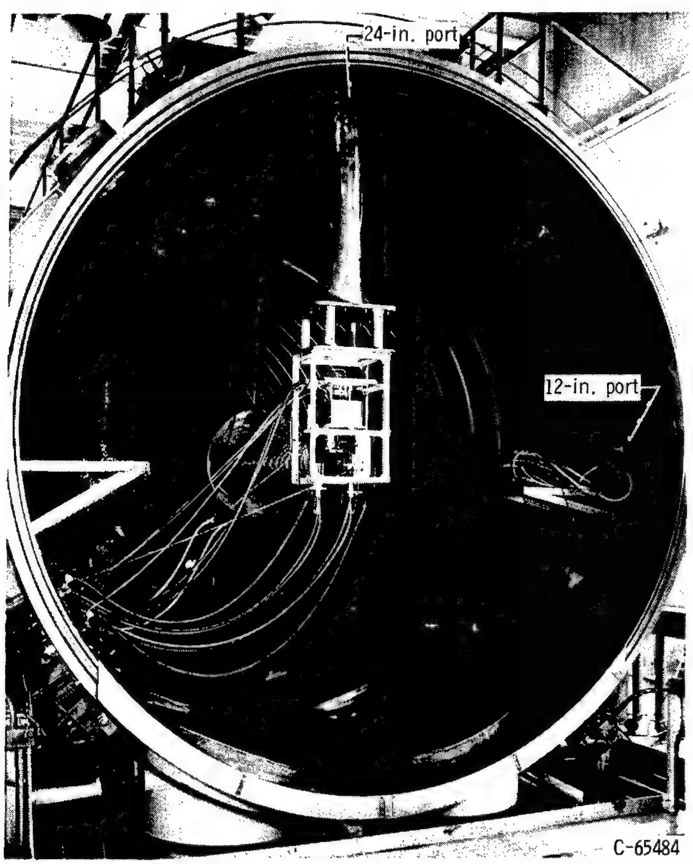

Figure 16. - Port-mounted thrustor.

pumps in operation to provide an order of magnitude indication of vibration conditions. For the design of ion-thrustor thrust stands or equipment where very precise information is required, vibration studies would be made in the exact location where the equipment would be installed. Measurements were recorded on the three axes shown in figure 15.

The vibration characteristics were detected with a piezoelectric accelerometer. The frequency range scanned was between 16 cps and 32 kcps. The maximum "g" condition occurred on each axis at approximately 3000 cps. At these maximum g conditions the displacement was less than 10^{-7} inch. Table III shows the maximum g loading for each axis and the corresponding frequency and displacement.

Model Installation

The 15-foot tank is designed so that models may be installed in any location to suit the requirement of the test. Large models may be handled in the tank with the assistance of an overhead monorail chain fall with a half-ton capacity. Models may be mounted from the walls or from one of the large port openings. A port-mounted model may be mounted on a port cover outside the tank. This has the advantage of providing a means of checking the mounting system prior to installation and simplicity of instal-

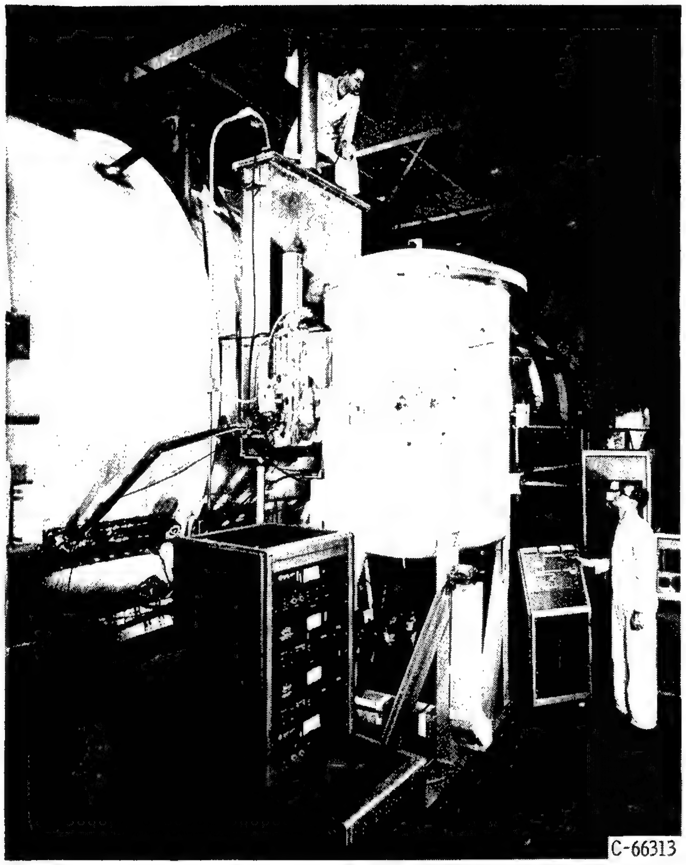

Figure 17. - Fast pumpdown tank.

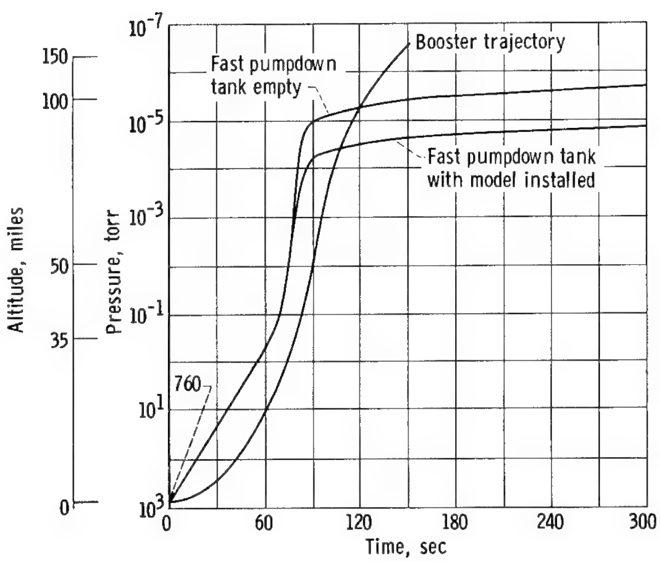

Figure 18. - Fast pumpdown tank performance data.

lation. A thrustor mounted from a 24-inch port and another mounted from the wall are shown in figure 16.

SPECIAL EQUIPMENT

Fast Pumpdown Tank

A fast pumpdown tank is available to simulate pressure conditions encountered in the early portion of a missile flight. This tank (fig. 17) is connected to the 15-foot-diameter tank by a 3-foot-diameter vacuum gate valve. It has an inside diameter of 46 inches and working height along the vertical axis of 70 inches. The top of the tank is removable for access to the model and for installation. Instrument, power, and service leads are fed into the tank through fittings mounted on three 12-inch ports on the side of the cylindrical tank. The tank pumpdown rate is compared with the pressure profile encountered during a booster flight in figure 18. Prior to the fast pumpdown tank operation, the 15-foot tank is evacuated and all pumps are kept in operation. The rotating piston pumping systems from either or both the 15- and 25-foot tanks are then used to reduce the pressure rapidly in the fast pumpdown tank to approximately 4 torr. The 3-foot valve is then opened to the 15-foot tank providing additional pumping. Condensable products are captured on the fast pumpdown tank

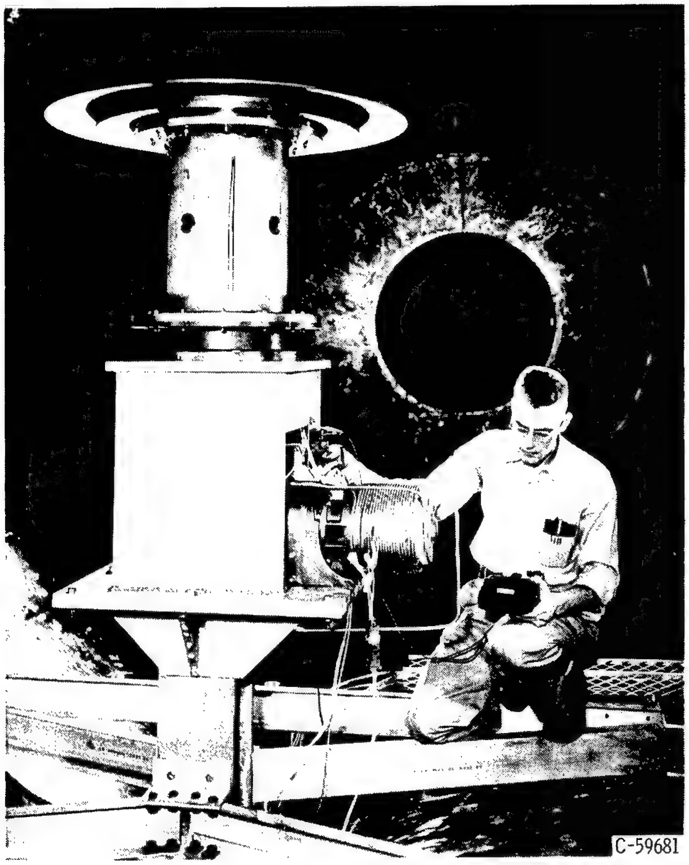

Figure 19. - Spin table with dummy load.

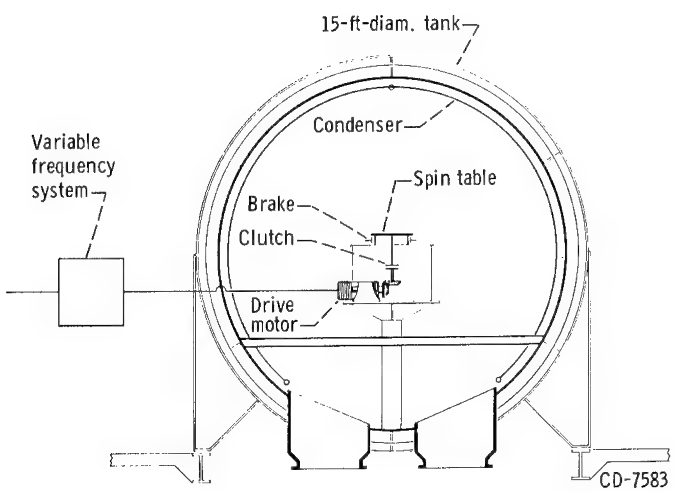

Figure 20. - Schematic of spin test apparatus.

condenser. The condenser is flooded with liquid nitrogen at the beginning of the pumpdown cycle.

Spin Test Apparatus

Figure 19 shows a spin test apparatus used in the 15-foot-diameter space tank for spin testing space payloads, components, or thrustors at controlled spin rates up to 282 rpm. Maximum clearance above the table is 8 feet with a side clearance of 5 feet. The spin table is approximately 20 inches in diameter and is driven through a shaft, electromagnetic clutch, and bevel gears by a variable-speed alternating-current induction gearmotor. Table rotation may be braked by an electromechanical braking unit. Figure 20 shows a schematic of the system. The variable-speed system consists of a direct-current motor with speed control driving an alternator at an infinite number of speeds. The speed of the gearmotor is a function of the frequency generated by the alternator and is adjustable up to full-field speed and can be maintained to 1 percent of a set value.

The spin table was operated in the 10^{-7} torr pressure range with a simulated SERT payload. This load had a weight of 278 pounds, a center of gravity 0.235 inch from the axis of rotation, and a moment of inertia of 7.45 slug-feet^2. The system accel-

erated to a speed of 282 rpm in 6 seconds and was braked to a full stop in $1\frac{3}{4}$ seconds with no overheating. With clutch disengaged, the unit coasted from 282 rpm to a stop in 7 minutes 35 seconds.

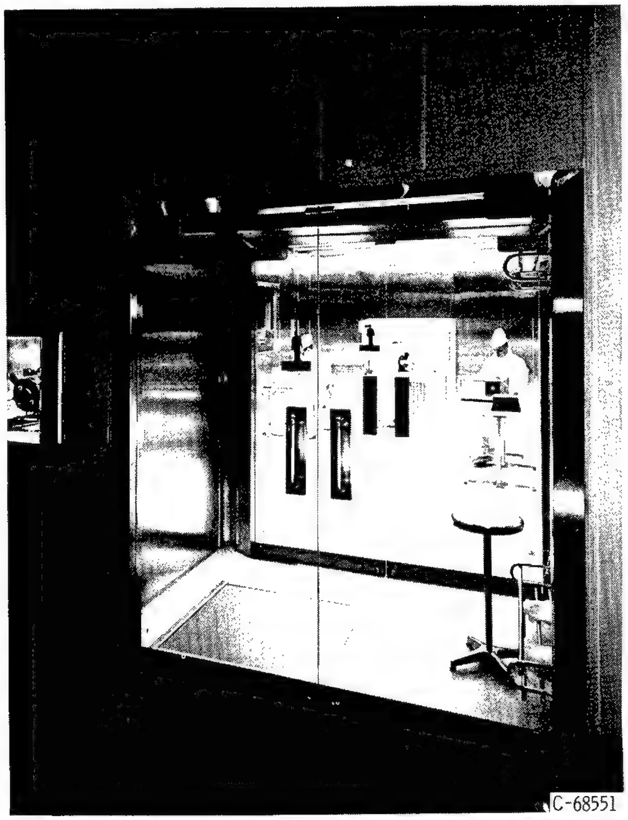

Figure 21. - Clean room.

Clean Room

A clean room is located on the first floor adjacent to the control room. The room, shown in figure 21, is a nonlaminar design meeting the particle size distribution curves for a class 10 000 clean room as defined in Federal Standard 209 - Clean Room and Work Station Requirements, Controlled Environment (ref. 6). Class 100 is achieved on the laminar flow clean bench in the room. Supply air for the room is passed through an absolute filter, conditioned to a relative humidity of between 30 and 45 percent, and can be maintained with $\pm 2^{\circ}$ F of any desired temperature between 65° and 80° F. A positive pressure of 0.05 inch of water is maintained in the room. The stainless-steel walls are grounded to eliminate dust attraction due to a static charge.

The room is 27 by 13 feet with a 9-foot 4-inch ceiling height. Access is through a 4- by 8-foot air lock equipped with a vacuum cleaner for cleaning equipment prior to being taken into the clean room. The air lock is also utilized as a change room. Double doors provide ready access for moving large units of equipment into the room.

Special equipment includes the laminar flow clean bench with a work area of 24 by 47 inches, a work table with sinks completely covered with a hood, work tables, and a sealer for enclosing equipment in polyethylene bags.

Electrical Power and Instrumentation Systems

The electrical system has been designed for flexibility in power sources and instrumentation to facilitate the operation of many different types of ion and plasma thrustors.

Direct-current high-voltage power supplies. - Since the potential requirements of

ion thrustors are many and varied, a modular system of power supplies is provided.

Twenty 10 000-volt, 10-ampere power supplies have been installed on the ground floor level of the facility. Output of these units goes through a patch board system to termination cabinets in the vacuum tank area. All 20 supplies can be used at the 25-foot tank while any 8 supplies may be used with the 15-foot tank. Power-supply output voltage is adjustable over the full range from 0 to 10 000 volts in increments of less than 1/2 of 1 percent of full scale. Full-scale adjustment time is approximately 2 minutes. Power-supply ripple under full-load conditions is less than 1-percent root mean square. Regulation is approximately 6 percent from no load to full load. The high-voltage output is fully floating so that the unit can be used as either a positive- or a negative-voltage supply. Both sides are insulated for 20 000 volts root mean square to provide for operating two supplies in series. Ballast resistors are provided to adjust the regulation of the supplies. Current and voltage measurements are also patched in as desired. Either the high or low sides of the lines may be metered; however, they require different instrumentation systems.

Overloads and faults will normally be detected by the overload trip mechanism in the power supply. This relay can be adjusted to trip at from 0. 025 to 10 amperes of current. When tripped, the power supply will automatically reset to zero before high

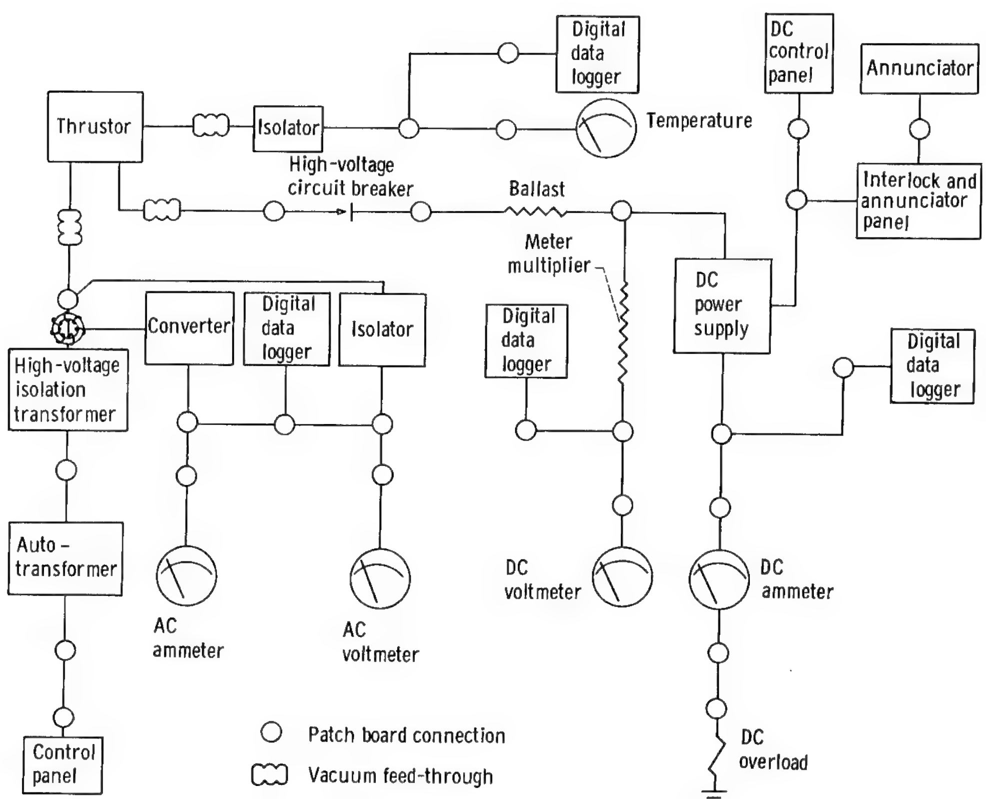

Figure 22. - Typical thrustor patching network (simplified).

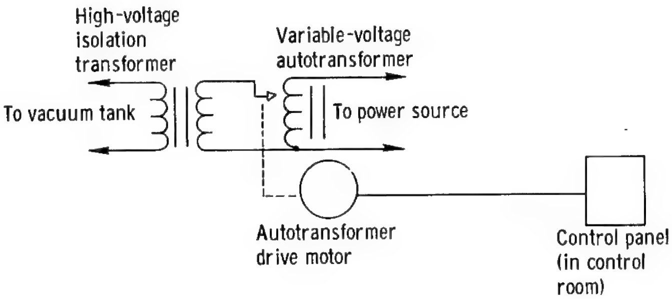

Figure 23. - Schematic of high-voltage isolation transformer system.

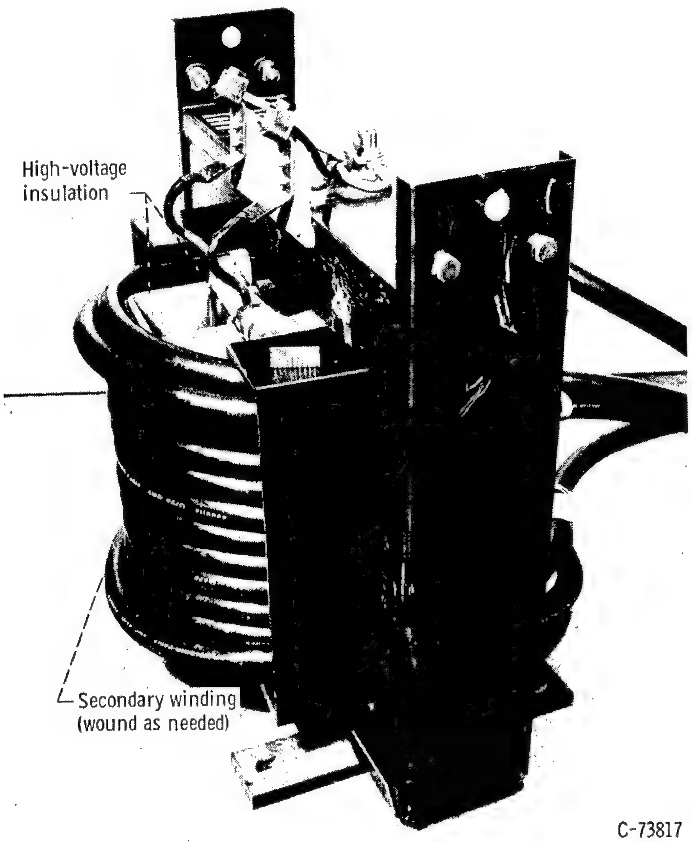

Figure 24. - High-voltage isolation transformer.

voltage can be energized. If this overload protection should fail, high-voltage 10-ampere fuses have been provided in the power-supply output. Should an internal fault occur, the input fuses and input circuit breaker are designed to protect the power supply.

Panels and connectors have been provided for the addition of multiple and/or automatic controls and insertion of external circuit elements in the high-voltage lines. A typical thrustor patching network is shown in figure 22.

Alternating-current power system. - In addition to the high direct-current voltage required for ion and plasma thrustors, alternating-current supplies are usually required for other thrustor functions. The ranges of voltage and current required by several thrustor types could not be supplied by any fixed set of power supplies. This led to the design of a system that employs 60 variable-voltage autotransformers in single- and three-phase configurations. Each transformer is capable of an output of 0 to 280 volts at 27 amperes. All are motor driven and can be remotely controlled from the control room. Time to vary the output voltage from zero to full voltage is approximately 30 seconds.

The voltage resolution of these units is equal to or greater than 1/2 of 1 percent at any point and output voltage is linear. Regulation of these transformers is such that there is no more than an 8-volt drop from zero to full current.

The output of these units is employed to power the primaries of high-voltage isolation transformers as shown in figure 23. The transformers (fig. 24) consist solely of the primary winding, core, and high-voltage insulation; secondaries are wound as

needed. At full input voltage the output windings have 3 volts per turn; theoretically, therefore, the highest current output obtainable from these units with a single-turn secondary is of the order of 2500 amperes. Where more current is needed, arrangement has been made to parallel more than one unit. Metering is accomplished by current and potential transformers located in the isolation transformer cubicle.

In many instances, direct-current power is required that is relatively low in voltage, but is intended to be biased to high potential with one of the high-voltage direct-current supplies. The low-voltage supply and metering are insulated for high voltage from line and ground. This supply is composed of one of the high-voltage isolation transformers wound with a suitable secondary and fitted with a solid-state bridge rectifier. The rectifier and all necessary filter chokes and condensers are mounted on an insulated base. The direct-current metering is accomplished by isolation amplifiers and clip-on direct-current ammeters. These units provide the necessary isolation to allow the measurements to be read at near ground potential in the control room. Inputs of all units are electrically identical, and all transformers draw primary power from the output of the variable-voltage autotransformers. Primaries of the autotransformers receive power from three-phase contactors in the motor control center, which can be operated from the control room.

Three-phase, 208-volt, 400-cycle power is available at levels up to 30 kilowatts. The alternating-current power system is compatible for use at this frequency, but the output is reduced by as much as 30 percent.

Miscellaneous power and instrumentation equipment. - This facility contains all instrumentation normally used in this type of research operation. Instruments such as oscilloscopes, vacuum tube voltmeters, X-Y plotters, instrumentation amplifiers, digital voltmeters, and oscillographs are available.

In addition to the control room equipment, an instrument calibration room has been set up for calibration equipment and standards. A calibration console has been installed for alternating- and direct-current voltage and current calibrations. Alternating-current ammeters measuring up to 50 amperes, alternating-current voltmeters to 1500 volts, direct-current ammeters to 30 amperes, and direct-current voltmeters to 750 volts can all be calibrated at an accuracy of 0.05 percent. Portable standards of 0.25-percent accuracy are also provided to cover these ranges.

A portable high-voltage direct-current supply of 50 kilovolts at 200 milliamperes is available along with a corona detector for high-voltage testing of components.

A small vacuum system is also available for checking ionization gages, Pirani tubes, and thermocouple gages at pressures down to 1×10^{-7} torr. Insulation can be checked by a high-resistance ohmmeter capable of measuring 5×10^{13} ohms at a 600-volt level.

A load bank of 100-kilowatt, 20-kilovolt capability is available for load checking

power-supply output and for providing higher percentage regulation capability of the high-voltage power supplies.

Measurements

Direct-current voltage and current measurements. - Direct-current voltage and current measurements comprise by far the majority of the data taken in the testing of electrostatic thrustors. These measurements can be divided into two broad categories: those at high common mode potential, and those at low common mode potential. Measurements at low common mode potential are the more readily performed and are discussed first.

(1) Current. The basic meter for current measurement is a 7-inch meter, 1-percent accuracy, with mirrored scale and knife-edge pointer. It has seven ranges, switchable by a knob on the front of the meter. These ranges are 0 to 10, 30, 100, and 300 milliamperes and 0 to 1, 3, and 10 amperes. The ammeters are patched into the low side of the power supplies in the high-voltage patch boards so that they read the current flowing between the supply and ground. For personnel protection, the ammeters are shunted by special resistors to prevent their being raised to high potential if the shunt should open.

(2) Voltage. The voltmeters for measuring the high potentials supplied by the direct-current power supplies are similar to the ammeters. In this case, a multirange milliammeter has been employed, in conjunction with a 10-megohm multiplier resistor. Employing the 0 to 0.1, 0.3, and 1.0 milliampere ranges provides voltage ranges of 0 to 1000, 3000, and 10 000. Extension of the ranges may be done by modifying the multiplier resistor at the patch board. All high-potential measurements are made to ground and are patched in at the high-voltage patch panels.

Measurement of differential voltage at a high common mode potential presents a problem that requires entirely different techniques from the low-potential case. In order for the readout units to be used in the control room they must be isolated from the high potential. In the case of alternating current this is relatively simple, but for direct-current measurements specialized instruments must be employed. The two basic direct-current isolation devices presently employed are a clip-on ammeter and a high-voltage isolating instrumentation amplifier.

The direct-current ammeter is basically a saturable reactor with the circuit element carrying the current acting as the control winding. In practice, the probe is a split ring-shaped device that is clipped over the current carrying conductor with appropriate insulation between them. The readout appears either as a meter reading at the instrument, or as a potential output that may be fed into a recorder or data logging

device. This instrument has ranges of 0 to 1, 3, 10, 30, 100, and 300 milliamperes and 0 to 1, 3, and 10 amperes full scale. Full-scale accuracy is ±3.0 percent and voltage introduced into the circuit by the probe is less than 15 millivolts peak. Alternating current with a peak value less than full scale affects direct-current accuracy less than 2 percent at frequencies different from the carrier (40 kc) and its harmonics.

The instrumentation amplifier is similar in many respects to the direct-current ammeter but is less complex. The input impedance of the amplifier is 200 ohms; input signals of 50 microamperes or 10 millivolts will cause a full-scale output. The input winding is isolated from output and ground for 40 kilovolts, and two molded polyethylene high-voltage connectors are provided for input connection. Two output signals are provided: first, 0 to 1 volt is for data logging purposes; second, 0 to 100 microamperes is for metering and oscillographs. This unit is sensitive to common mode alternating current at its exciting frequency (60 cps) and its harmonics. A 67-cycle supply overcomes this problem.

Voltage measurements at high common mode potential can be made using either one of these isolation units in conjunction with resistors placed across the source and reading the current. Calibration curves would then provide the translation into voltage.

Alternating-current voltage and current measurements. - The alternating-current voltage and current measurements are made with the same equipment for both high and low common mode potentials. The current measurements are accomplished using ring-type current transformers, in which the current carrying conductor is the primary. By using suitable insulation between the current transformer and the cable this measurement can be made at any potential. The output of the transformer is fed into a current converter that translates it into a 0- to 5-milliampere direct current, which is then read on dual range (0 to 2.5/5 ma) 7-inch meters. Measurement accuracy is a sum of the inaccuracies introduced by the current transformer (1.0 percent), the converter (1.0 percent), and the meter (1.0 percent). Where greater accuracy is desired, the system can be calibrated as a whole, thus eliminating much of the inaccuracy. A selection of current transformers is available to cover the range from 5 to 1000 amperes with no degradation of accuracy.

Alternating-current voltage measurements are accomplished using unity ratio potential transformers with 40 000-volt insulation between the primary and secondary and the primary and core. Three ranges of potential transformers are provided, 3 to 30, 10 to 100, and 30 to 300 volts. These transformers provide unity transformation within ±1.0-percent accuracy when used within their specified ranges. The output is read on 7-inch multirange alternating-current voltmeters.

The accuracy of this system is the sum of the transformer accuracy (1.0 percent) and the voltmeter (2.0 percent). As in the case of the current measurement, system calibration can reduce this error.

Temperature measurements. - Temperature measurements, like those of voltage and current, must be made on components that are at either low or high potential relative to ground.

The low-potential case presents no particular problem other than those normally encountered. Certain aspects of this system are unusual for a facility of this size. Basically, the system is a millivolt measuring device with a basic range of 0 to 20 millivolts. All lead wire is copper telephone cable extending from the control room to the vacuum tanks. At the tank, thermocouple alloy wire from the thrustor is terminated at terminal strips on a cold junction reference chamber. Cold junction thermocouples may be of any type, although iron constantan, copper constantan, and Chromel-Alumel are normally used.

Readout equipment consists of six potentiometer-type precision indicators with a 48-point pushbutton switch for each. Each switch has 50 extra wire pairs for future expansion. Provision for a maximum of 600 thermocouples has been made. Thermocouple leads terminate at a multiple point patch panel for patching to a digital data logger independent of the switch. The potentiometers have scales commensurate with the type thermocouple and its range. In general, these scales are all interchangeable with no modification to the instrument.

Analog recording of steady-state and transient temperatures can be made on direct writing oscillographs employing light-sensitive self-developing paper.

Temperature measurements of high-voltage components in the engines must first be isolated using the high-voltage isolating instrumentation amplifiers. Once this is done, the output may be handled the same as the low-potential measurements. This system is limited to the response time of the instrumentation amplifier, which is approximately 2.5 seconds. Normally these measurements are not made with as great precision as the others, so ambient temperature will usually suffice for cold junction reference.

The accuracy of both systems depends on the precision of the indicating device, which in the case of the potentiometer is of the order of 0.2 percent of full scale. In the case of high-voltage measurements, the errors due to the isolation amplifier and readout are approximately 3 percent. Errors in the high-potential temperature measuring system are the sum of the 0.2 percent in the potentiometer, 1 percent in the instrumentation amplifier, and the normal changes in ambient temperature. Additional details concerning the cold junction reference system and the use of the thermocouple system are included in appendix A.

Layout of Equipment

Control room. - The control room (fig. 1(a), p. 2) is on the first floor of the

Operations Building, between the two vacuum tanks, with its long axis parallel to the tanks. All four sides have windows for visually checking the operations. The room is equipped with relay rack cabinets to house control and instrumentation panels. In the center of the room is a hollow rectangle of forty-four 77-inch-tall upright racks (fig. 1(a)); low silhouette consoles (76) have been provided around the periphery of the room to allow for the installation of control panels without obstructing the view through the windows. Turret cabinets (86) have been placed above each console and the doors at the ends of the control room. All racks are designed to accept standard 19-inch wide relay rack panels.

Control and instrumentation cables are terminated on vertical panels recessed in the base of each rack and console. These cables originate at the patch panels on the ground floor. All control panels and instrumentation equipment plug into connectors and receive power and signals from these cables. The turrets also have termination panels, with cables originating at the low silhouette cabinets. These cables are inserted into receptacles in the floor cabinets as needed.

Patch panels. - All research wiring for this facility has one end terminated in a large patch board complex (fig. 1(b)) in the ground floor level of the building. The patch board system is divided into three sections; high voltage, control, and instrumentation. Patching between these three sections may be accomplished within the limits of safety.

(1) High-voltage section. The direct-current output from the high-voltage power supplies is connected to a main distribution panel. From here, cables are run to two sets of high-voltage patch panels. The high-voltage patch panels serve to route power to each of the vacuum tanks; thus, any power supply may be used with either tank. Since all high-voltage supplies are fully floating, both positive and negative leads may be patched. The method of patching the supply determines the polarity of the high side. The patch board system allows the supplies to be put in either series or parallel or in series-parallel arrangements to increase voltage or current capabilities.

Ballast resistance from the high-voltage load bank may be placed in series or shunt with the supplies. Metering, either of the high or of the low side of the supplies, may be patched in, as can overvoltage and overcurrent devices. The high-voltage cable employed in this system is a common polyethylene coaxial cable (RG 8/U).

Low-voltage control and metering signals from the supply may be patched into the control system cables.

(2) Control cable section. The control cable system is comprised of 12 conductors, shielded cables number 16 AWG (American Wire Gauge) terminated on quick-disconnect multiple-pin receptables. These cables provide the ability to connect the alternating- and direct-current power and data system from the control room to the tank area.

(3) Instrumentation cable section. Three types of instrumentation cables are employed in this facility: 52 pair telephone cables, coaxial cables, and the seven-wire,

shielded, general purpose cables. The telephone cables are not patched from the ground floor patch board complex and, therefore, will not be described here.

Low level signals (mV) are handled through standard coaxial cables of the type RG 58/U, which is a 52-ohm cable that terminates on ultrahigh frequency connectors on the patch boards and termination panels. These cables are suitable for all applications where low-loss, low-noise characteristics are deemed necessary.

For general purpose instrumentation, a seven-wire, number 20 AWG, shielded cable has been employed. This cable is normally employed for use with the ionization gage system and all other high-level transducers systems as required.

Appendix B contains a more detailed description of patching between these systems.

SAFETY SYSTEMS

Annunciator System

In relatively complex systems such as are described here, it is necessary to provide a warning system in order to locate a fault quickly. An 80-channel solid-state annunciator system has been installed that receives signals from jacks in one section of the interlock panel. These annunciator drops provide visual indication of any interlock or safety switch that is not in its proper position when the test is ready to be run. In addition, all power-supply overloads will operate drops when faults occur in the output of the supply. Extra drops have been provided for monitoring research ciruits. Each annunciator panel (8 readouts) may be positioned anywhere in the control room.

Signals to the annunciator system are in the form of contact closures or openings (either may be used, requiring only the changing of wire jumpers in back of the panel unit). Both audible signals and repetitive flashing of the annunciators legend panel provide warning of a fault. When the acknowledge button is depressed, the audible signal will cease and the legend will glow brightly. With the removal of the fault condition, the legend will return to a dimly glowing (or normal) condition.

Key Switch and Interlock System for High-Voltage Circuits

Since the possibility exists that high voltage may appear at either one or both of the tanks and at associated termination and patch panels, it becomes a necessity to have a clearly defined safety system. At the same time, the system cannot be so complicated so as to make it difficult to get the system to operate. The possibility of unauthorized personnel operating the system must also be taken into consideration.

The approach followed was to interlock all panels that were potentially hazardous and to provide each tank high-voltage system with different master key locks. Only one key is available for each of the two systems.

The key for each tank operates the master power switch on all high-voltage power supplies used in conjunction with the tank.

In series with the key switch on each tank system are interlock switches on all the cabinets that might contain high voltage. In each patch and termination panel area there has been placed a "Safe-Run" switch. This is a manual turn switch that interrupts the safety system in order to prevent the systems being inadvertently energized while someone is working in a cabinet or on the thrustor. Provision has been made in the system to patch in extra interlocking which may be changed from test program to test program.

Visual audible signals have been provided to give warning when the high-voltage system on either tank has been armed. Upon the actuation of the key switch for either tank, the audible alarm for that tank (a horn for the 25-ft tank, a buzzer for the 15-ft tank) sounds for 5 seconds. After this period, the high-voltage permissive system is then energized. With the completion of the key switch circuit, the rotating beacon signals on the tanks and the high-voltage patch boards start operating and continue until the completion of the test. The 25-foot tank high-voltage system operation is identified by rotating red beacons on the tank and the patch boards. The 15-foot tank employs yellow beacons for the same purposes.

CONCLUDING REMARKS

The layout and performance of the electric propulsion laboratory facilities of the NASA Lewis Research Center have been described. These facilities consist primarily of two large vacuum tanks, together with related support equipment. Tests can be conducted in both facilities in the 10^{-7} torr range. The electrical and instrumentation systems are designed to handle a variety of thrustor types at power levels up to the megawatt range. Both tanks have been in successful operation on research programs since 1962. These tanks are suitable for a wide variety of experiments and preflight tests requiring large-volume vacuum environment.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 14, 1965.

APPENDIX A

THERMOCOUPLE REFERENCE SYSTEM

The thermocouple reference chamber is a box 12 inches on a side by 18 inches high (fig. 25). The reference junction thermocouple wires pass through a gasket to reach an ice bath inside the chamber. The bath is an aluminum pot filled with a water and glycol solution. Attached to the bottom of the pot is a bank of Peltier effect thermoelectric coolers. The hot junctions of these thermoelectric elements are cooled by a flow of city water supplied through a 1/4-inch tube attached to the elements. Power for the thermoelectric elements is supplied by a low-voltage, high-current, direct-current power supply mounted in the base of the reference chamber cabinet. The bath is insulated on all six sides by 4 inches of fiberglass wool insulation. A thermistor mounted permanently on the bath operates a sensitive meter relay to maintain the temperature of the bath at the required 32° F. The mass of the bath and of the water is large and the heat loss of the system is low so the cycling of the system is very slow. In use the system is quite stable since it is never turned off and is only disturbed when thermocouples are added or removed. The thermocouple reference junctions are insulated with a thin coating of epoxy resin or varnish to provide insulation to prevent accidental shorting and consequent crosstalk between channels.

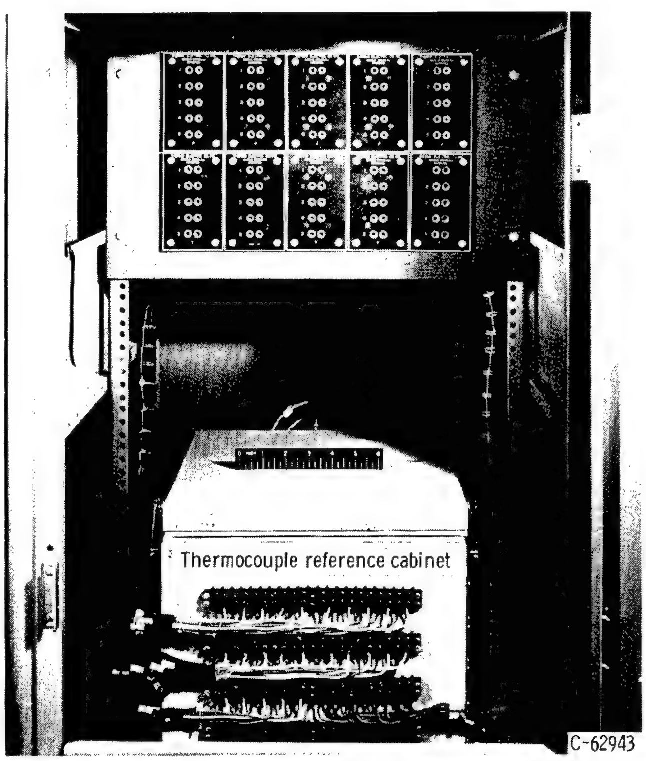

Figure 25. - Tank termination cabinet 6M.

Terminal strips are mounted on three sides of the reference chamber cabinet. Three terminals are provided for each channel of thermocouple data for a total of 100 channels. When a thermocouple is installed on the tank, leads are brought to the termination cabinet containing the reference chamber and attached to two of the terminals. A reference thermocouple of the same alloy wire is fabricated and inserted into the bath. One lead is terminated on the terminal containing the same alloy wire from the measuring thermocouple. The other is terminated on the remaining empty terminal. A wire pair

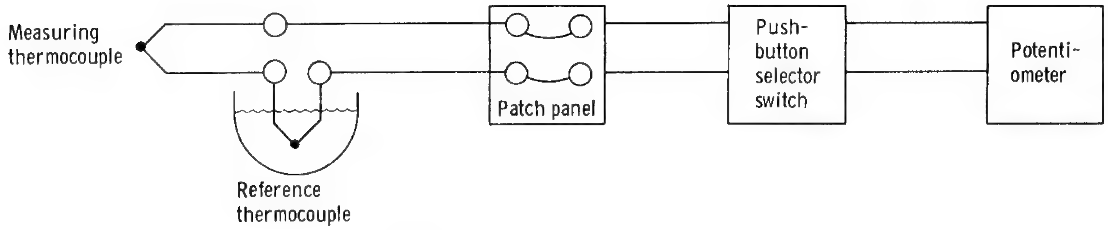

Figure 26. - Typical thermocouple circuit.

TABLE IV. - THERMOCOUPLE RANGES

Thermocouple type	Temperature span, ^{o}F	Output, mV
Copper constantan	-300 to 570	20.07
Chromel Alumel	32 to 900	19.88
Chromel Alumel	900 to 1800	20.74 + 19.88
Iron constantan	32 to 700	20.48
Platinum - platinum 13 percent rhodium	32 to 3000	19.56

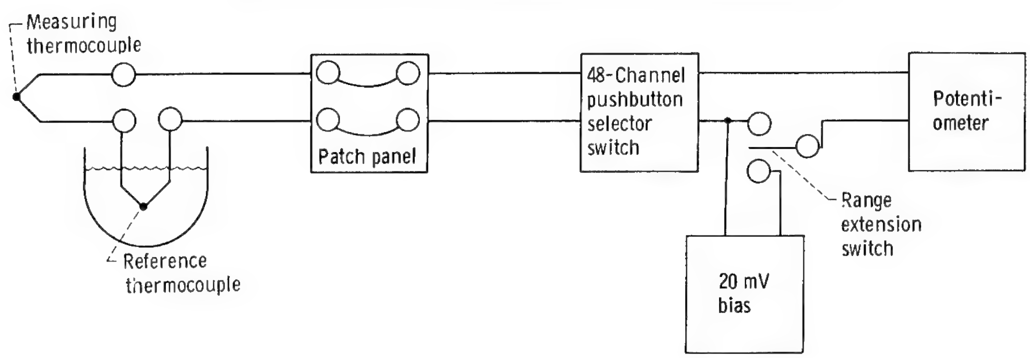

Figure 27. - Thermocouple circuit with bias supply for range extension.

from the copper wire cable from the control room is terminated on terminals containing the leads from the measuring and reference thermocouples (see fig. 26). For greater accuracy both alloy leads may be provided with cold junctions.

The insertion of two jumpers into the proper channels in the computer-type patch panel in the control room completes the circuit, and the temperature measurement may be made by either a multichannel self-balancing potentiometer or on the digital data logger system.

As mentioned previously, the self-balancing potentiometers in the control room all have one range, 0 to 20 millivolts. Since all alloy junctions stop at the termination panel next to the vacuum tank, the system can be handled much as any other voltage measuring system. The choice of 20 millivolts as a span for the measuring instrument was a

compromise dictated by examining the output of several of the most commonly used thermocouples over their normal range. These parameters are tabulated in table IV.

Except for the Chromel-Alumel high-temperature thermocouples, one 20-millivolt instrument will suffice to read the outputs of these thermocouples; only the scales will need to be changed in order to make the instrument read temperature directly. For the Chromel-Alumel thermocouples, a 20-millivolt bias supply is switched in series opposing with the measuring system to allow the higher range to be read (fig. 27).

Each measuring instrument has a 48-channel pushbutton system associated with it to allow instantaneous selection of the desired thermocouple. If a mixture of thermocouple types are desired to be read on one instrument, it is only necessary to provide a multiple scale on that unit. The thermocouple reference can be checked at any time by placing the measuring thermocouple in an external ice bath. If the reference bath is at ice water temperature, then a null reading should be detected on a sensitive potentiometer or galvanometer.

APPENDIX B

PATCH PANELS

In the patch system described herein provision has been made to cross connect or break into a circuit easily. All 7- and 12-wire cable patch panels have been provided with fanning strips (figs. 28 and 29). These strips are connected to receptacles on the panel. When cross connection is desired, a jumper is patched from the incoming cable receptacle to one of the fanning strip receptacles. Cross connections are then made to adjacent terminals that are cabled to another panel receptacle. This is then patched to outgoing cabling.

Figure 30 illustrates a typical patch. The connection to the digitizer system is also shown. All digitizer connections from the 7- or 12-wire cables must be performed at these patch panel fanning strips.

When relays are desired in the circuit, patch connections are made to the multiple control panel (fig. 31). At this panel all cables terminate on fanning strips. Relays are mounted behind the panel with contacts and coils brought out to fanning strips. Power

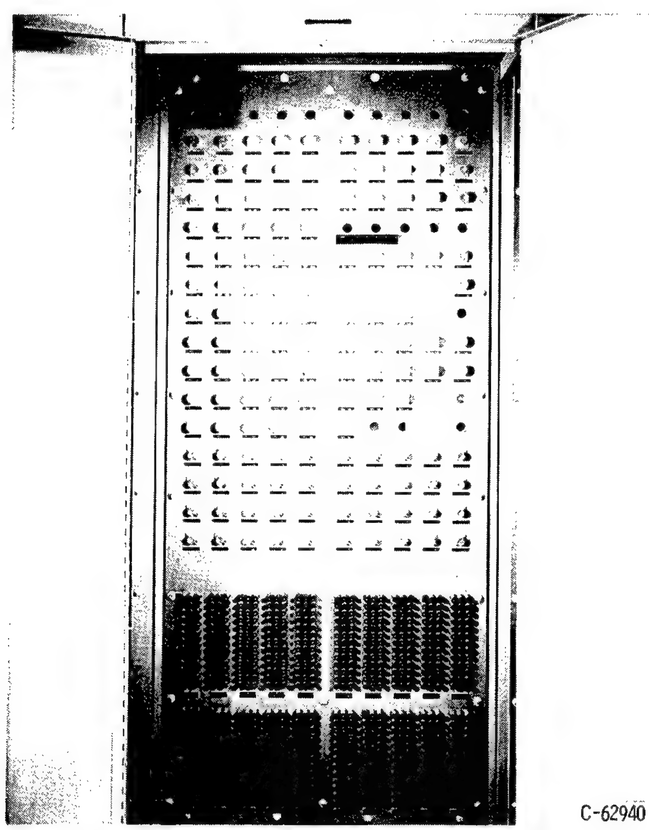

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Figure 28. - Control cable patch board.

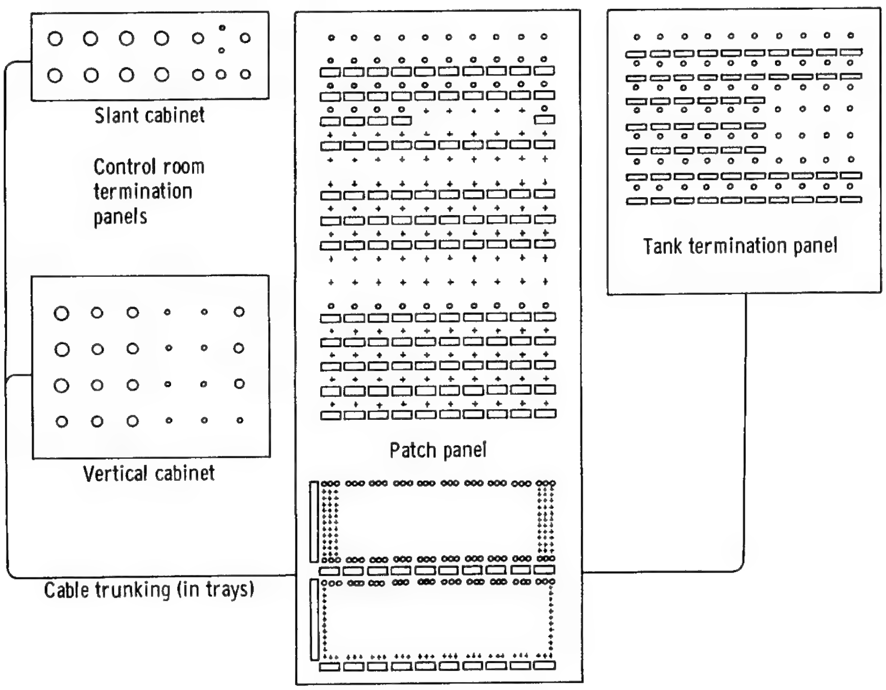

Figure 29. - Control cable patching system. Block diagram of typical cabling interconnection - in this case, the 12-wire control cable system.

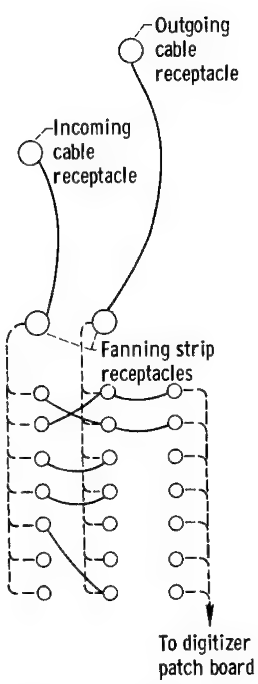

Figure 30. - Typical patch.

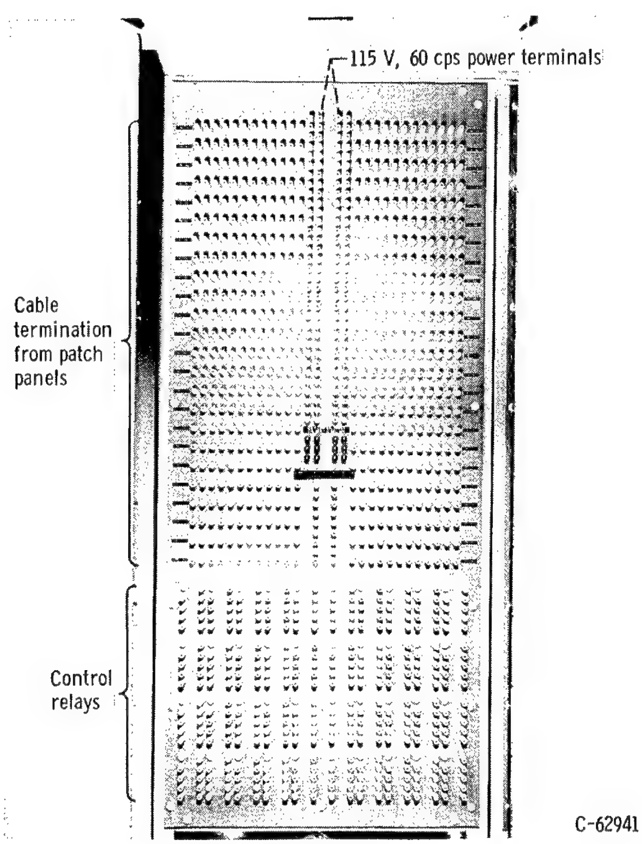

Figure 31. - Multiple control panel.

feeds are also terminated in this fashion. Single-wire jumper leads are connected between wiring from the patch and relay terminals (see fig. 32). These leads may be either terminated in banana plugs, spade lugs, or the insulation simply stripped back 1/2 inch, since the binding posts employed will accept any of these.

The patch panels also provide room for mounting additional circuit elements. For example, vacuum high-voltage circuit breakers have been mounted for use with clusters of ion thrustors. Extra openings have been left in all panels for the addition of receptacles when needed.

All cables in this system have been shielded and the shields terminated to the shells of the receptacles. Receptacles are mounted on insulated panels, so that no grounding is done except at special instrumentation ground busses at the tank end of the cable system. Multipin jumper cables are also shielded. In the case where the cable is patched through the fanning strips, the shield is carried through as an extra wire. The instrumentation ground bus is insulated from the building throughout its length and is terminated in copper plates buried in the ground outside the building.

The high-voltage section of the patch board system (fig. 33) is physically separated from the rest of the system and is electrically interlocked to prevent accidental injury to personnel. The boards are constructed of 1/2-inch-thick acrylic plastic. This material was chosen because of its high resistivity, low moisture absorbtion, arc resistance characteristics, and transparency. Notwithstanding the superb electrical characteristics of this material, the patchboard is not depended on for high-voltage insulation. The high-voltage connectors themselves will support up to 40 000 volts direct current for short times. These connectors are molded polyethylene, with the connector manufactured as an integral part of the cable. This construction prevents formation of corona discharges throughout the voltage range and subsequent degradation of the insulation due to production of ozone. The high-voltage cabling is run through special cable trays that are painted bright red for easy identification. These trays are kept separate from the power and instrumentation cable trays to prevent possible crosstalk of high voltage into the low-voltage systems. Although each patch board is an entity in itself, the side panels between these boards have been removed to allow interconnection between boards. The doors on the cabinets have been provided with acrylic window sections to enable inspection of the interconnects without disturbing the interlocking by opening the doors.

All cables in the system have a number code (table V) associated with them. Each cable number is unique; the code number at each receptacle provides a great deal of information about the nature and routing of the cable. The cable code designation at the receptacle tells the type of cable, the destination of this particular cable, and the cable number. A typical connection from tank to control room is shown in figure 34.

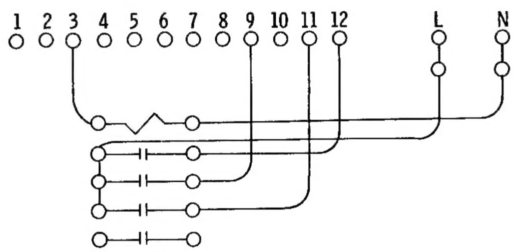

Figure 32. - Typical relay patch detail for 120 volts, 60 cps.

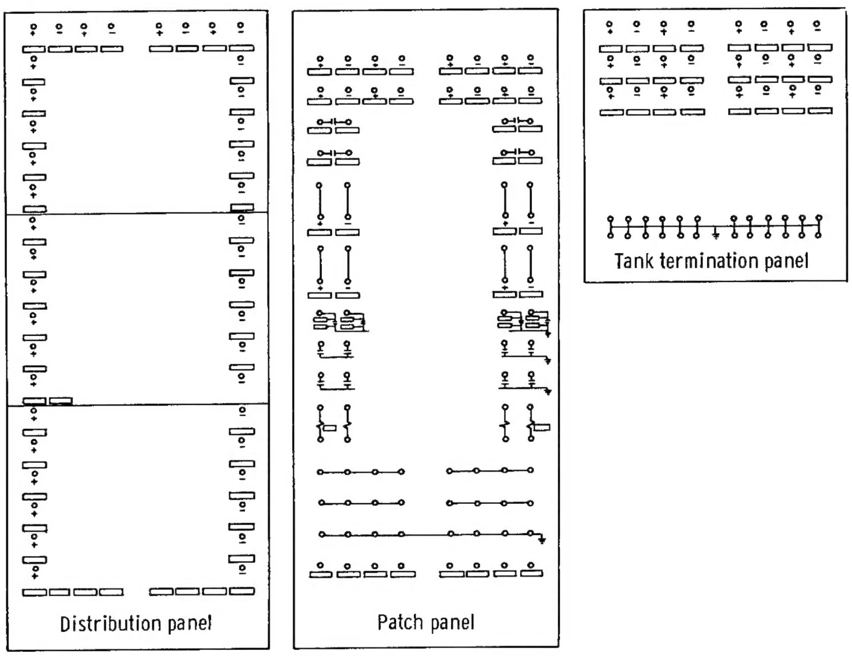

Figure 33. - High-voltage patching system.

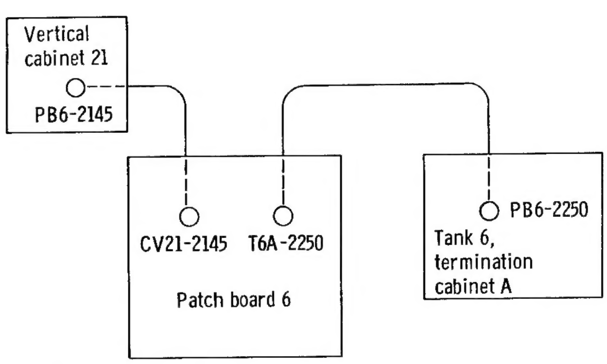

Figure 34. - Typical connection from tank to control room.

TABLE V. - CABLE DESIGNATION CODE-RESEARCH WIRING[a]

[Cables are designated as if originating in the first-floor patch boards.]

Designation	Definition
Terminations	
CS	Cable to control room slant cabinet
CV	Cable to control room vertical cabinet
FS	Cable to fanning strips
IA	Cable to interlock and annunciator panel
HV	Cable to high voltage direct-current supply patch boards for metering
MC	Cable to multiple control patch panel
PC	Cable to powerstat variable alternating-current supplies for control
PM	Cable to powerstat remote output panels for metering
PS	Cable to high-voltage direct-current power supplies - control
T	Cable to tank termination cabinets
PB	Cable to patch board
Series	
1001 - 2000	"A" type 12-conductor cable; 16 AWG with shield 19/29
1001 - 1300	To control
1301 - 1450	To high-voltage direct-current power supplies
1451 - 1500	To alternating-current transformers
1501 - 1550	To interlock patch board
1551 - 1600	Not assigned
1601 - 1700	To tank termination cabinets
1701 - 1900	Not assigned
1901 - 1999	For high-voltage direct-current metering
2001 - 3000	"B" type 7-conductor cable; 20 AWG with shield 7/29
2001 - 2400	To control room
2401 - 2760	To tank patch panels
2761 - 3000	To fanning strips
3001 - 4000	"C" type coaxial cable RG-58/U
4001 - 5000	"D" type cable, 3-conductor shielded
5001 - 6000	52-Conductor (26 pair) telephone cable
6001 - 7000	"A" type 12-conductor cable for fanning strips

[a]For example, in the cable number CS5-2145, CS is the general termination, 5 is the specific termination (cabinet, panel, etc.), and 2145 is the series designation number.

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